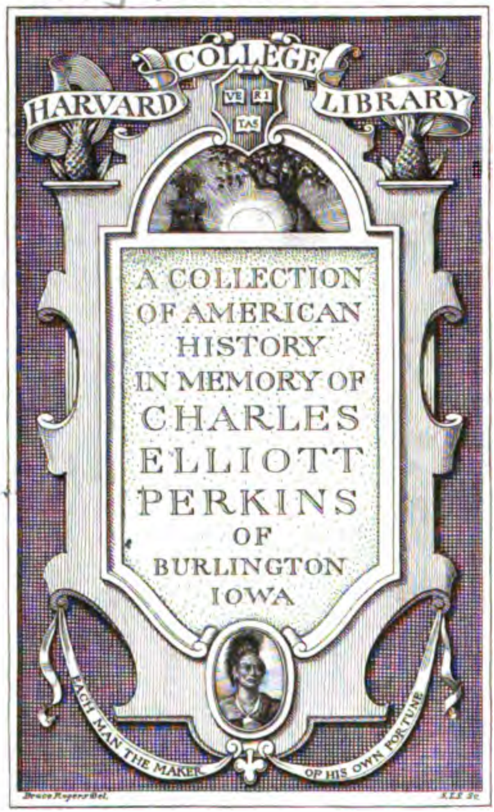
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A COLLECTION OF AMERICAN HISTORY IN MEMORY OF CHARLES ELLIOTT PERKINS OF BURLINGTON IOWA
EACH MAN THE MAKER OF HIS OWN FORTUNE

ADDRESSES AND PAPERS

OF

JAMES B. EADS,

TOGETHER WITH A

BIOGRAPHICAL SKETCH.

COMPILED AND EDITED

BY ESTILL McHENRY.

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[NOTE.—The "Jetty System Explained," running from page 171 to page 207, contains some matter from preceding papers. The repetition is due to the fact that a pamphlet was made up in the summer of 1874, for gratuitous distribution, as a means of instructing the public in regard to the jetty project, and necessarily the arguments previously submitted to Congress were to some extent reproduced. As the "Jetty System Explained" was largely instrumental in effecting the passage of the jetty act of March 3, 1875, it seems proper to preserve it entire in this connection.]

Biographical Sketch.

James Buchanan Eads, an American Engineer, was born in Lawrenceburgh, Indiana, May 23, 1820. His parents went to St. Louis, Missouri, in 1833, where he has since resided. Owing to his father's misfortunes he ceased to attend school at the age of thirteen. During five years he was employed as a clerk in a dry-goods store. Having great mechanical ingenuity and a fondness for mathematics and physical science, all of his spare moments were devoted to the study of engineering and its cognate sciences.

In 1839 he was employed as a clerk on a Mississippi river steamer.

In 1842 he constructed a diving bell boat to recover the cargoes of sunken steamers on that river. Soon afterwards he designed larger boats with novel and powerful machinery for pumping out the sand and water and lifting up the entire hull and cargo of the sunken vessel. The field of his operations finally embraced the entire river and included its principal tributaries. A great many valuable steamers were set afloat and restored to usefulness by his methods, although before they were devised it was deemed impossible to save the wrecked vessels on that river, owing to its shifting sands and rapid current, which soon caused them to become buried in its deposits and to disapear beneath its muddy waters.

In 1845 he erected at St. Louis the first glass-works built west of the Ohio river.

In 1856 Mr. Eads made a proposition to the Government to remove the snags and wrecks obstructing the channels of the Mississippi, Missouri, Ohio, and Arkansas rivers, which passed the House of Representatives, but failed, for want of time, in the Senate.

In 1861 he was invited by President Lincoln to visit the capital for consultation as to the practicability of using light-draft iron-clad vessels on the Mississippi river and its tributaries. He soon after designed and constructed a powerful squadron of eight steamers

having a speed of nine knots an hour and aggregating five thousand tons. These were all completed, plated with iron, fully equipped and ready for their armament of one hundred and seven large guns within the astonishingly short period of one hundred days.*

These were the first iron-clad vessels constructed by the United States, and several of them on the 5th of February, 1862, were engaged in the capture of Fort Henry, more than a month before the fight of the Merrimac and Monitor.

In 1862-3 he designed and constructed six turreted iron vessels, all heavily plated. The turrets on these were quite different from those of Ericsson and Coles. The guns in them were worked entirely by steam. The eleven and fifteen-inch guns could in this way be loaded and discharged every forty-five seconds. This was the first application of steam in manipulating heavy artillery.

In 1867-74 he designed and constructed the famous steel arched bridge over the Mississippi river at St. Louis. Its central arch has a clear span of five hundred and twenty feet, and the side arches are five hundred and two feet each. Its granite piers all rest upon the bed rock underlying the river deposits. Two of them are much deeper than any yet built. One of them, weighing forty-five thousand tons, was sunk to the bed-rock one hundred and thirty-six feet below high-water mark, through ninety feet of sand and gravel. Another, weighing forty thousand tons, is founded on the rock one hundred and thirty feet below high-water mark. Many novel devices were designed by him in the construction of the caissons, by which these enormous pieces were sunk through the sand to the rock. These improvements were adopted in sinking the deepest pier of the East River suspension bridge. The arches were built out from the piers until they met at the centre. The half spans near the shores of the river were upheld by huge iron guys passing over temporary towers on the piers, and anchored securely on shore. On the central piers the half spans balanced each other, being built out from opposite sides of each pier.

As a steel or iron column is shortened when a load is put upon it, so the arches of the bridge are shortened by their own weight when resting against their abutments. They had to be designed 2½ inches too long for the space between the abutments to allow for this initial compression. The arches are composed of four curved ribs formed of an upper and lower line of steel tubes 18 inches in diameter, strongly braced, about 12 feet apart. Each individual tube of the system is about twelve feet long. The method of erection adopted by the contractors was different from that intended by Mr. Eads, and resulted in leaving the central space between the half arches 2½

* See First volume, page 498, "History of the Navy during the Rebellion"—Appleton.

inches too short to receive the central tubes; and as the contractors had constructed each tube according to Mr. Eads' designs, they refused to complete the work of erection so far as it related to the insertion of these central tubes because they were too long for the space. The problem of how to insert them was thus left for Mr. Eads to solve. If these tubes were reduced 2½ inches in length before insertion, the arch would have been several inches too low to suit the roadway when the support of the guys was withdrawn. The financial wants of the Bridge Company required Mr. Eads to visit London just before the first arch was closed, but before leaving he designed a set of tubes for closing it that could be shortened or lengthened at will. This was done by cutting each one of the original tubes in two parts and joining the two severed parts by an internal iron plug on which was turned a right and left screw which fitted into corresponding threads turned on the inside of the tube ends. Several inches of the tubes' length were cut out to permit it to be shortened up, so as to enter the space. Through the plug, pin holes were made for the insertion of strong levers by which it could be turned. By this simple method all these enormous arches were closed.

There exists a popular belief that the insertion of these tubes was accomplished by contracting all of the other tubes constituting each half-span of an arch, by the application of ice, whereby the space in the crown of the arch was sufficiently enlarged to receive the central tubes as originally designed.

When the time arrived for closing the first, or western arch, an effort was made to insert the unaltered central tubes of the eastern one (which were of the same size) into it, by attempting to contract the arch with ice. About sixty tons of ice were applied to it, but after several days had been spent in the experiment, it was abandoned, and the extension tubes, designed by Mr. Eads, were inserted without difficulty, in a few hours. The ice experiment was made in his absence, and without his approval or knowledge.

After the extension tubes were inserted and coupled at each end to the others, the plugs were turned to extend them until the arch was of the desired length. The steel which had been cut out of each tube was then replaced by two semi-circular pieces, of the same quality and diameter of the tube. These enclosed the exposed part of the plug, and they are held on it by riveted bolts which pass through it, so that it is difficult to detect the difference between these and the other tubes, while they are fully as strong. The screw plug was not put in the middle of the tube, as the bending of the tube might thereby be more likely to occur under great pressure. It was therefore placed near one end of it.

The next great work executed by Mr. Eads was the deepening of the mouth of the Mississippi River.

During the last forty years various plans to accomplish this were tried, without success. In 1872 a commission of seven distinguished engineers of the United States army were charged by act of Congress with the solution of this important problem. They recommended, in 1874, the building of a canal through the left bank of the river, near Fort St. Philip, to connect it with Breton Bay, by which the bars at the mouth would be avoided entirely. This plan was stoutly opposed by Mr. Eads, in several pamphlets upon the subject, in which he favored an open mouth for the river, and asserted the entire feasibility of deepening the bar of one of the passes by building parallel jetties out into the sea across it, to prevent the river from spreading out as it enters the gulf, thereby losing its velocity and its power to sustain the sedimentary matter with which its waters are heavily charged.

Mr. Eads was vigorously opposed by the Chief of Engineers of the United States Army, and by nearly all of the members of the corps. Confident of the correctness of his views, he challenged the attention of Congress and the country by the fearless proposition to undertake the deepening the mouth of the South West pass by jetties, to the depth of thirty feet, at the sole risk of himself and his associates, without demanding any pay whatever from the Government until after twenty feet should have been secured; the normal depth on that bar being about fourteen feet.

At the time this offer was made a committee of the House of Representatives had unanimously reported a bill to appropriate eight million dollars for the construction of the canal recommended by the United States Commission. It had been the invariable policy of the Government to entrust the designing and executing of all works of river and harbor improvement to its military engineers alone, and the proposition to transfer the most important one it had ever undertaken to a civil engineer and private citizen, and to permit him to apply a method that had just been condemned by the report of six out of seven of the most distinguished engineers of the army, met with the most decided opposition. The offer of Mr. Eads, however, was so manifestly to the interest of the Government, and his reputation as an able and successful engineer had been so well established by the construction of the iron-clads and the St. Louis bridge, that Congress determined to seek more light upon the subject and therefore referred the question to another commission composed of three engineers from the army, one from the coast survey, and three civil engineers. Nine months afterwards six members of this commission reported in favor of applying the jetty system at the mouth of the smallest of the three passes (the South pass) on the bar of which there was but eight feet of water and at the upper end of which, a shoal with but fourteen feet on it obstructed its connection with the river. The arguments of Mr. Eads in favor of the

larger pass were, however, so convincing, that the House of Representatives (which had at the previous session voted the eight million dollars recommended by one of its committees to begin the canal,) now passed the jetty bill by an almost unanimous vote for the large pass, in spite of the recommendation of the commission of engineers to improve the small one. But the action of the House was not concurred in by the Senate, and the bill was finally amended and made to apply to the little pass. He was therefore compelled to accept the South pass or see the plan he had urged so pertinaciously, executed by the corps of engineers who had so strenuously opposed him. Instead of one single bar with fourteen feet on it, he was now compelled to undertake two of them; one in the sea with but eight feet on it, and one in the river with but fourteen feet on it. The opposition to Mr. Eads' plan of improvement and the numerous predictions of its failure, induced Congress to insert in the act the most stringent conditions.

The sum agreed to be paid for the work was five and one-quarter million dollars, which was considerably less than the estimate of the Commission. Only half a million dollars of this sum was to be paid after the jetties and auxiliary works should have secured a channel two hundred feet wide and in no part of that width of less depth than twenty feet. When a channel twenty-two feet deep and two hundred feet wide was secured, another half million was to be paid, and similar payments were to be made on attaining twenty-six and twenty-eight feet respectively.

It was predicted that the bar would re-form in front of the jetties, and the expense of extending and maintaining them was estimated by the commission to cost one hundred and thirty thousand dollars per annum. This extension and maintenance was undertaken by Mr. Eads for thirty thousand dollars per annum less than this estimate, and as a guarantee to the Government that it should not cost over one hundred thousand dollars per annum for twenty years, he consented to allow the Government to retain one million dollars of the price of the jetties after it should be earned as a pledge to insure the maintenance of the thirty feet channel for that period, at that price per annum. The act provided that the works should be of the most permanent character, but left him the fullest latitude in the design, location and construction of them. To secure the first payment, at least one-half of the whole work had to be executed, and before twenty-two feet was reached, eighty per cent. of it was completed. At this period the terms of the act proved so oppressive that he was compelled to ask Congress to modify them. His energy, skill and good faith, had been so evident that an advance of one million dollars was promptly voted to enable him to prosecute the work. In the Senate this measure was opposed by only two votes, and in the House by only fifteen. The bill also provided that a

commission of five army engineers should inspect the works and report in full regarding them and their effects, and also what further measure of relief would be proper to extend to Mr. Eads. This report was very favorable so far as it related to the permanency of the works and of the channel, and of the deepening of the sea bottom in front of the jetties where a new bar had been predicted, but it advised against any further payments beyond those provided in the jetty act. Congress however, took a different view of the matter. Being satisfied from the report, that at least seventy-five or eighty per cent. of the work had been executed, and that it was destined to be entirely successful, a further advance of seven hundred and fifty thousand dollars was promptly voted. This is probably the only instance in the history of the Government where money has been voted to an individual in advance of the specific terms of an agreement, and the fact of one and three-quarter million dollars being thus voted to Mr. Eads must be accepted as a remarkable evidence of its confidence in his plan of improvement, and of its appreciation of the magnitude of the difficulties which had been overcome by him.

On the 8th of July, 1879, the United States inspecting officer at the jetties, reported that the maximum depth of thirty feet had been secured through the jetty channel, and that the least width of the twenty-six feet channel through the jetties was two hundred feet. The remainder of the four million two hundred and fifty thousand dollars was thereupon paid to Mr. Eads and by the terms of the act the remaining one million dollars is deemed to have been earned and is bearing five per cent. interest. Four years and six months interest has already (1884) been paid to him, and four and one-half years maintenance likewise. It may therefore be safely assumed that the Mississippi jetties have proved entirely successful.

Mr. Eads is a tireless worker, and has written several essays and delivered a number of addresses during the last nine years, in favor of the application of the jetty system of improvement to the Mississippi River throughout its entire alluvial basin. His plan is essentially a high-water treatment of the river, and is one never before proposed. It contemplates the reduction of widths of the river where they are excessive, by contracting the high-water banks at such places, and thus create a comparative uniformity of width of its flood channel throughout the alluvial district. This reduction of width is to be accomplished by permeable willow dams, or screens, placed where it is desirable to create new shore lines. The slight retardation of current which these cheap structures will cause, will be sufficient to insure a rapid deposition of the sedimentary matters carried in the flood waters. The uniformity of width will produce a uniformity of depth, and secure at least twenty feet, at low water, from Cairo to the Gulf. Uniformity of width and depth would insure

uniformity of current, and a uniform charge of suspended sediment, and this would virtually stop the caving of the banks, for these are caused by changes in current velocity. Narrowing the wide places would lessen the frictional resistance to the flow of water through them, and by thus facilitating the discharge of the floods, would lower their heights, and thus greatly lessen the need of levees. This plan involves the absolute conservation of the entire flood waters in one channel, and is therefore the antithesis of the outlet system, which proposes to deplete the river in flood time to prevent overflows. In support of his system, Mr. Eads calls attention to the fact that all sediment-bearing rivers throughout the world present one common feature, which proves the importance of conserving the floods in the main channel to secure the full benefit of their erosive forces, by which the bed is deepened and the flood line, or surface slope, is lowered. This common feature is, that the larger the flood volume flowing in one channel through alluvial districts, the lower will be the surface slope, or fall, per mile. Hence to lessen the volume flowing in the bed of the Mississippi is to insure a greater elevation of its surface slope, and thus necessitate still higher levees. His system does not involve the straightening or shortening of the river. He claims that an intimate relation exists between the velocity of the current and the quantity of sediment carried in suspension in the water, and that the least retardation of the normal velocity will cause a deposit to be thrown down on the bottom, which is simply an effort of the river to restore the necessary velocity by building up the bed and increasing the surface slope. When this is built up sufficiently, the current will be restored and deposit will cease. Conversely, any acceleration of the current causes the water to take up from the bottom an additional amount of sediment. This deepens the bed, lowers the slope, and brings down the current to its normal velocity; after which further erosion ceases. The wide places are the disturbing causes, because they prevent a uniform velocity. They cause the depositing and the erosive actions to be constantly alternating, and thus create caving banks and cut-offs, and rapid changes in the channel. They also increase the height of the floods by requiring steeper slopes, at such places, to overcome the greater frictional resistance to the current caused by larger surfaces of the bed being in contact with the water.

Congress, in 1879, authorized the creation of a mixed commission of civil and military engineers, to be called the Mississippi River Commission, and to be composed of seven members, of whom Mr. Eads was one. It was made the duty of this Commission to prepare a plan for the improvement of the navigation of the river, and to prevent destructive floods. In the first report of this Commission, the views advanced by Mr. Eads upon this important question, years ago, have been accepted and fully indorsed.

In addition to giving the channel of the Mississippi a low water depth of 20 feet to Cairo, it is claimed by Mr. Eads that a district as large as the State of Indiana, constituting the alluvial basin of the river, will be saved from overflow almost without the need of levees, by this method of improvement. The magnitude of the benefits which would accrue from this extension of deep water navigation, eleven hundred miles from the gulf into the very heart of the Mississippi valley; and the absolute reclamation of such an enormous area of rich lands below the mouth of the Ohio, is too vast to be foretold in this century.

Immediately after the publication of the proceedings of the Inter-Oceanic Canal Congress, held at Paris under the auspices of Count De Lesseps, in 1879, Mr. Eads published a letter in the New York *Tribune* containing a project for a ship railway across the Isthmus of Tehuantepec, Mexico, as a substitute for the sea level canal proposed by that convention. Among other arguments advanced by him in support of this method are: First.—The railway can be built for one-quarter of the cost of the canal. Second.—It can be built in one quarter of the time. Third.—It can transport the ships with absolute safety, more rapidly. Fourth.—Its actual cost can be more accurately foretold. Fifth.—The expense of maintaining and operating it will be less than that of a canal. Sixth.—Its capacity can be easily increased to meet the future requirements of ocean transportation. Seventh.—It can be located at many places on the isthmus where a canal is wholly impracticable. Mr. Eads is now (1884) pressing this important matter with his usual energy.

In 1878 Mr. Eads made an elaborate report upon the improvement of the mouth of the St. Johns River, Florida, in response to the request of the municipal authorities and citizens of Jacksonville; and in 1880, having been requested by the Governor of California to act as Consulting Engineer of that State, he visited the Sacramento river and reported upon the plans for the preservation of its channel, and the arrest of *debris* from the mines. At the request of the Minister of Public Works of Canada, he in 1881, examined the Harbor of Toronto, and submitted a report upon the measures required for its improvement. All these reports were exhaustive and eminently instructive in their treatment of the subjects discussed.

Having visited Mexico in the interest of his Tehuantepec Ship Railway project, Mr. Eads was in 1882 commissioned by the Mexican Government to examine the port of Vera Cruz, and to suggest the kind of works necessary to render the entrance safe, and to protect shipping inside. His suggestions were approved by the Government, and movements inaugurated to construct the necessary works. He also reported upon the harbor of Tampico, and his suggestions are under consideration by the Government, which will no doubt embody them in works as soon as the condition of the treasury

ADDENDUM.

In June, 1884 (while this book was in press), Mr. Eads received a letter from "The Society for the Encouragement of Arts, Manufactures and Commerce," — organized in England in 1754, and incorporated by Royal Charter in 1847, — informing him that the Albert Medal had been awarded to him as a token of their appreciation of the services he had rendered to the science of Engineering. This medal was founded in 1862, in memory of His Royal Highness the Prince Consort, and is awarded annually by the Society, — of which His Royal Highness the Prince of Wales is President, — for distinguished merit in promoting arts, manufactures or commerce. Mr. Eads is the only American who has been thus honored.

will permit. When ready to return to the United States a Mexican ship of war was detailed for his passage.

In the course of his visits to Europe Mr. Eads has inspected the mouths of nearly every river emptying into the Baltic Sea and the German Ocean. He has also inspected the Rhone, the Danube (including the works at its mouth) and the Theiss in Hungary; and also the Suez, Amsterdam, and Rhone Ship Canals.

Early in 1884, the city authorities and people of Galveston, Texas, solicited Mr. Eads to undertake the improvement of their harbor and the entrance to it. He replied that for a stated sum he would undertake the work, payments only to be made as depths of channel should be secured. A bill was accordingly presented in Congress by the Texas representatives, and is now (May, 1884) under consideration by the proper committees.

In the meantime, at the solicitation of the "Mersey Docks and Harbour Board," of Liverpool, England, Mr. Eads has examined, and in a lengthy and forcible paper reported upon the Estuary and Bar of the Mersey, giving conclusive reasons for the opinions advanced.

ADDRESSES AND PAPERS.

BY JAMES B. EADS.

ADDRESS

To the Pupils of the Night Schools of the Polytechnic Institute of St. Louis, 1859.

My Young Friends, and Gentlemen of the Polytechnic Night Schools:

It has seldom been my good fortune to witness a scene so pleasing to my feelings as the one before me. I see here a multitude of the intelligent, industrious and energetic youth of St. Louis, who have been diligently seeking after knowledge through the past winter evenings. Whilst many of those who have labored by your side through the day have spent their evenings in idleness, dissipation or crime, you, actuated by a higher impulse and a nobler aim, looking upward and onward, have chosen the pleasant path of instruction as the certain highroad to honor, to fortune and to happiness.

You are assembled here this evening to listen to words of advice and encouragement, and to receive the rewards your diligence has merited. After listening to the very able and eloquent address of my friend, Chancellor Hoyt, I feel that I can scarcely hope to interest you. My efforts will, however, have the merit of brevity, if they have no other recommendation.

When I say to you that it gives me great pleasure to see you, I will say at the same time that I feel the deepest regret that I was not born an orator for this particular occasion. If I were, I would urge you with all the power and earnestness of eloquence to persevere in the pursuit of knowledge. I would picture to you the wonderful age in which it has been your good fortune to be born. I would paint to you the vast resources of the young but mighty nation of which each one of you constitutes an honorable member; and I would

prove to you, if I had the eloquence I so much desire, and would fasten it upon your memories forever, that it is in the power of each one of you, by being honest, industrious and watchful over the interests that are confided to your care, and by continuing the studies you have begun, to win for yourself a name that shall be an honor to you and to your parents, and to your children after you, no matter what branch of industry you may select, or where you may choose to locate yourself.

You are not living in a land where nobility of birth, like a rich mantle thrown over the grave, hides the inactivity and corruption which lie beneath it. You are living in a country where every man is valued according to his worth, and according to his intelligence, and according to his ability to promote the public good.

Now, so far as the first of these tests is concerned, it is in your power to win a high character for worth, by being strictly virtuous and upright in your dealings; by obeying the laws of God and your country, and by obedience to your parents, masters and employers. With regard to the second, the aid which this institution offers to you through its night schools, its library, its reading rooms and its lectures, the amount of knowledge which each one of you is capable of acquiring is absolutely without limit. And just in proportion as you are intelligent will be your power to promote the public good.

The world is not ruled now, as it once was, by chivalry. Neither is it ruled by religious fanaticism. It is not ruled now, as it once was, by the sword; neither is it by the pen. A mightier ruler is monarch of the world now. Commerce is that monarch. Commerce, with her iron scepter! Commerce, with her breath of steam! Commerce, with her nerves of lightning! Commerce, whose voice controls grim-visaged war! Commerce, the ruler of kings! Commerce, whose ships gather her tributes from the uttermost parts of the world! At whose command the depths of the sea, and the bowels of the earth, yield up their treasures. At whose word mountains are pierced through and oceans united. Commerce, the annihilator of space, the builder of cities, and the founder of empires. Commerce, who blesses the broad earth with Peace, with Plenty, and with Happiness. Who scatters with liberal hand honors and fortunes broadcast over the land. This is the migty monarch who rules the world now, and you who are found in the factory, the foundry, the workshop, and in all the busy marts and channels of trade are her children. You are her best beloved; and to you belongs the rich inheritance of her favors. Commerce is no friend to the blockhead and the idler. But just in proportion as you have knowledge and indnstry will you be able to secure wealth and distinction at her hands.

In the vast regions which stretch away westward to the Pacific Ocean, where the bear and the buffalo roam in security, will be wrought changes that will surpass the story of Alladin and his won-

derful lamp, or any other magical tales you ever read. Many of you will witness these wonders, and many of you will be the master spirits to bring them about.

Where the Indian hunter now tracks his game will be seen comfortable farmhouses, lowing herds, green pastures and rich fields of waving grain. The war whoop and the savage yell will give place to the cheerful song of the harvest home or the shrill whistle of the locomotive. Towns, villages, factories and mighty cities, all teeming with a happy, free and enlightened people will cover the land. The arts, sciences, literature and religion will flourish in it, and wealth and refinement will make this busy scene their home.

This grand field of enterprise is open to you all, and it is in the power of each one of you to be a man of mark in it. But, my young friends, you may rest assured that you never can become so, that you never can become great men, or even prominent men, without study and labor. Not the study and labor of an hour, or of a month, but constant unintermitting study and labor. Men may be born white or black, rich or poor, but they never are born great men. Greatness is the reward of study and labor alone.

Study and labor should go hand in hand together, for labor is absolutely necessary to give strength and vigor to the intellect, while the intellect is just as absolutely neecessary to give dignity and honor to labor. Without knowledge what better would we be than mules or oxen? Not a whit. Then seek knowledge with all your energies. There is no pursuit more profitable than the pursuit of wisdom.

"Happy is the man who findeth wisdom and the man that getteth understanding: for the merchandise of it is better than the merchandise of silver, and the gain thereof than fine gold. She is more precious than rubies, and all the things that thou canst desire are not to be compared unto her. Length of days is in her right hand, and in her left hand riches and honor.

"Her ways are ways of pleasantness and all her paths are peace. Exalt her and she shall promote thee. She shall bring thee to honor when thou dost embrace her. She shall give to thine head an ornament of grace. A crown of glory shall she deliver to thee."

These are the words of King Solomon, who was counted the wisest of men. They were uttered nearly three thousand years ago, and have lost none of their force by age. They are the truest of all the true words in the Old Testament and deserve to be written upon the memory of every boy in the land.

Acquire wisdom and all the high places and honors in the land are within your reach. Knowledge works wonders, and who dares say that the destinies of this great nation will not one day be swayed by one of the very pupils I am now addressing?

I had intended, my young friends, to advise you upon many subjects of deep interest to you this evening, but the limited time I have

allotted to myself will prevent me from more than touching upon a few of them. I cannot let this opportunity pass, however, of urging upon you with all the power and earnestness which I am capable of commanding, to make *truth* and *honesty* your constant companions. Never lose sight of them. Make these two words, *honesty* and *truth*, your watch words through life. Bind them about your fingers and write them upon the tables of your hearts. Be honest and truthful for your own sake. Be honest and truthful for the sake of your parents, that you may not bring their gray hairs in sorrow to the grave. Be honest and truthful for the sake of your brothers and sisters, that no tinge of shame shall burn their brows. Be honest and truthful for the sake of your eternal welfare. If all these considerations fail to keep you from dishonesty, let me conjure you to be honest from policy. You will find nothing more true than that "honesty is the best policy." If you feel no moral obligation to be honest, be so from policy. The man who is known to be honest and truthful, if failure or misfortune overtake him, will find friends ready and willing to aid him. But the dishonest man will be left to aid himself as he best can. No man but a fool, an absolute fool, will be dishonest, and no one but a coward will tell a lie. Well hath the poet said that "an honest man is the noblest work of God."

Another thing, my young friends. Do not neglect your employer's interests. Do not put him to useless expense or waste his property. Do not idle away the hours that should be devoted to his service. No matter if he be a hard master. No matter if he be mean. No matter if he be stingy. No matter if he be cross or cruel. Do you do your duty. Do you be too noble minded and good to neglect the interests confided to your care. You will not be with him long, and by studying his interests you will inculcate such habits of care, economy and industry as will be a fortune to you when you begin business for yourself. The man who neglects his employer's interests will be sure to neglect his own. It is mean and dishonest to neglect his interest, and by studying his interest you will learn how to promote your own, and thus your virtue will be rewarded.

Never be ashamed of honest toil. Never be ashamed to say you work for your living. Never be ashamed of the trade which supports you. Never be ashamed of earning your living by the sweat of your brow. When I see a man or boy who feels above those who work for their living, I pity him from the bottom of my heart. I feel that he has been badly raised; that his education has been sadly neglected, and I think that if the time ever does come when it will be necessary for him to earn a living by the sweat of his brow that there is great danger he will prefer to steal it. I would as soon think of being ashamed of my mother as to be ashamed of labor. Labor does that for you in your youth and manhood that your mother did for you in your infancy. She gave you food and clothing, and taught your

young heart heavenly piety and virtue. Labor gives you comforts and plenty, and teaches you manly independence and self-reliance. I would as soon be ashamed of my mother as to be ashamed of labor.

Ashamed of honest toil! It is the fountain from whence we draw our health and happiness. Ashamed of intelligent labor! It is the mine where we gather wealth and power. It is the foe of vice, the companion of honesty, and the twin brother of triumph!

Labor is the shield which the Almighty has interposed to protect all those domestic virtues which cluster round the hearth stone—as love, gentleness, truth and chastity,—virtues which give us a foretaste of heaven by making our home a paradise.

Labor, when coupled with knowledge, becomes a mighty engine of power. If you have knowledge your energies will make the State more powerful. If you have knowledge your patriotism will make the liberties of the commonwealth safer. If you have knowledge, from your own ranks will the rulers and elders of the land be chosen.

True greatness is found in other places than on the battle field or in the Senate Chamber. The man who can by his inventive genius cheapen light or heat or the supply of water to the masses is greater than a general.

He who taught us how to seize the very lightnings of heaven and make them obedient messengers to flash our thoughts across an ocean or a continent, is greater than all the Cæsars and Napoleons the world ever saw. The name of Morse deserves to live as long as the thunderbolt which he taught to labor for the common good shall be heard reverberating in the regions of space.

He who by his genius can cheapen bread or clothing to the poor, or any one of the common necessaries of life, as sugar, salt, soap or fuel, deserves the thanks of the nation, and to have his name inscribed in the temple of fame.

Perhaps a reward as great as this may be even now awaiting the humblest of my hearers. Let me conjure you not to permit ignorance to deprive you of so great a glory.

ADDRESS OF WELCOME

To President Andrew Johnson, on his Arrival at St. Louis, September 9, 1866, with General Grant, Admiral Farragut, Wm. H. Seward and Gideon Welles.

Mr. President:—The citizens of St. Louis, irrespective of party, through me, their humble instrument, tender to you and to your illustrious counsellors and companions, the hospitalities of this city.

In bidding you welcome, I shall but poorly perform the grateful duty with which they have honored me, if I fail in assuring you that their greeting is no formal lip-service, where the heart is absent.

When you see their city, the vast creation of a few short years, reposing like a youthful giant by the side of its nurturing parent—the great Father of Waters—and witness the sinews of its strength and discover the secret of its growth, you will learn that its destinies are controlled by scores of thousands of earnest men, who are toiling with hand and brain in the upward and onward road of human progress.

They have sent me with their welcome. They know that you have sprung from their own ranks, and they love you as one of their own. They are familiar with every page of your instructive history, and they honor you because that record sheds luster upon themselves. They feel, too, that you have, by your indomitable will, sound judgment, and inflexible patriotism, achieved the highest pinnacle of human greatness. Your heart and soul, your hopes and sympathies, have been constantly identified with the workmen of the nation.

Therefore, while it would be idle for me to say that none differ with you in opinion upon public questions, I can safely assure you that all unite in extending a cordial welcome to one who has whispered hopes to the humble, raised poverty to eminence, and placed fresh laurels on the brows of labor.

Your friends have witnessed with breathless anxiety your heroic contests with the enemies of the Federal Constitution. They, sir, have been taught to revere that instrument, as the highest law of the land. We have no sovereign in this nation to give our allegiance to, but THE LAW—the written law; and he who is not loyal to that has treason in his heart. While all other officers of the Government promise to *support* that ægis of our liberties, you alone, sir, by its wise provisions, are required to swear that you will *defend* the Constitution of this Republic.

We thank God for the faith that is in us, that you will continue to defend it successfully against all its enemies, until a united, prosperous and happy country rewards your devotion.

Again, sir, on behaf of those whom I represent, and the millions from here to the shores of the Pacific, I bid you welcome.

ADDRESS

On Behalf of the St. Louis Merchants' Exchange, to the Grand Convention for the Improvement of the Mississippi and its Tributaries. St. Louis, February 12, 1867.

Mr. President and Gentlemen of the Convention :

The St. Louis Merchants' Exchange desires to express to each one of you the assurance of its most cordial welcome.

Through one of its members it begs to lay before your honorable body some of the weighty considerations that have moved it to solicit your valuable co-operation in effecting the grandest national enterprise of the present age.

The improvement of the Mississippi river and its great tributaries is a work which not only deeply interests each member of this imposing assemblage, and the vast constituency whom it represents, but in some degree affects the welfare of every citizen within the limits of this whole commonwealth. Fully conscious of the importance, the gravity and the grandeur of the issues and interests involved in the discussion of this subject, I cannot but regret the partiality which has assigned this honorable duty to one who is painfully sensible of his inability to perform it properly. It involves the contemplation of one of the sublimest physical wonders of a beneficent Creator; the consideration of its inestimable social and political value to the favored people who are its possessors, and the question of the power of man's genius to control and direct its mighty currents obedient to his will.

We cannot contemplate the manner of its creation, and the numberless ages required to fit it for man's uses, without the deepest

reverence for the power and wisdom, and the most fervent gratitude for the ceaseless bounty of our Heavenly Father. Through countless centuries, long before a human form had reflected the image of his Maker on this planet, we know that this restless stream, whose branches receive their limpid tributes among the highest passes of the Alleghanies and the Rocky Mountains, was being prepared by an all wise Creator for man's dominion. Through those dark eras, of which the only record is found on stony tablets among whose sundered leaves and upheaved masses human lore has traced the marvelous history, the old Father of Waters was silently spreading his fertilizing floods over the vast plains that lie between those mountains on the East and West, and which extend from the cold highlands of the Lake of the Woods and the Assiniboin, far away to the sunny clime where milk-white harvests unfold their downy treasures amid cypress groves and the fagrant perfume of the magnolia. Through that long tide of years he was slowly but incessantly creating and enriching this immense valley which is now justly known throughout Christendom as the "Garden of the World."

The boundless reservoirs which supply its channels through such long periods of the year, and make it so valuable to man, and which, if opened simultaneously, would overwhelm the valley and mar its usefulness, are, with that thoughtful care which orders all things wisely, unlocked in regular succession, month after month, by the touch of Spring, as she advances from her home in the tropics to bless with her genial presence the icy regions of the North.

This giant stream, with its head shrouded in Arctic snows, embracing half a continent in the hundred thousand miles of its curious net work, and coursing its majestic way to the Southern Gulf, through lands so fertile that human ingenuity is overtaxed to harvest their productiveness, has been given by its Immortal Architect, every mile of it, into the jealous keeping of this Republic.

The garden which it beautifies and enriches contains seven hundred and sixty-eight millions of acres of the finest lands on the face of the globe; enough to make more than one hundred and fifty States as large as Massachusetts. Acres of the choicest soil in profusion, sufficient to duplicate proud England twenty-four times over. More territory than the areas of Great Britain, France, Spain, Austria, Prussia, European Turkey, and the Italian Peninsula combined. If peopled as Massachusetts is, it would contain five times the present population of the whole United States. Populated as France is, it would hold as many people as the whole area of Europe contains. Peopled as Belgium and the Netherlands are, and with not half the danger of famine or starvation, it would contain four hundred millions of souls—largely more than one-third of the entire population of the world. Human comprehension cannot grasp the grandeur of such an empire. Human wisdom cannot estimate

the wonderful value of such an inheritance, over every acre of which the banner of this Republic floats supreme.

This great valley lies between those parallels of latitude that are known to be most conducive to health and to the development of the mental and physical energies of man. In its capacity to produce the cereals, grasses, cotton, sugar, tobacco, hemp, vegetables and fruits of every kind; in the richness and variety of its mineral wealth, the grandeur and value of its forests, its inexhaustible quarries; in a word, in all the natural resources which conspire to increase the wealth and power of a people, the bounty of Providence has been most wonderfully manifested.

The stream which in every direction penetrates this favored region, and is the grandest feature of North America, holds in its watery embrace the destinies of the American people. Sooner or later it must give to the dwellers within this valley power and dominion over the whole boundless continent. It is the great arterial system of this Republic, whose heaven-wrought channels should teach the people who possess them that the Almighty designed them to dwell in love and harmony forever as one nation. There is not a drop within its noble veins, that is not loyal to the Union. No effort can be made to sunder the Union that will not vibrate the alarm along its sensitive courses to their most distant and delicate extremities. Its vital branches and wonderful reticulations permeate and envelop the great body of our country, giving unity to amplitude, value to productiveness, and to the State resistless power, and an existence as enduring as human liberty and intelligence. Through its copious channels, for all time to come, are destined to circulate the sustenance and surplusage of its people. Life-giving commerce, who brings in her ever welcome train peace and good will to men, through its many convenient passages will distribute plenty and prosperity throughout the realm. The wealth and luxuries of the generous South will thread its devious currents to their very sources, and will be scattered within the sound of their tinkling rills and sparkling cascades, whilst every wave that is borne towards the gulf will be burdened with the reciprocated offerings of the colder latitudes. From its streams will be sent forth to the less favored nations of the earth, the bountiful abundance of a land far more blessed than that which the prophet of old was permitted to gaze upon, but forbidden to enjoy.

The influence and power of the people of this valley will be limited only by their virtue and intelligence. They can forever rivet to this Union with bonds firmer than brass or steel the States that lie beyond the mountains, outposts of the nation, and which, fringing the commonwealth, constitute buttress and bastion, stockade or portcullis, to give safety and repose to the mighty State within their borders. Self-protection, community of interest, ties of consan-

guinity and national pride, will hold those States to the great central empire as immutably as the planets are held in their just positions by the attraction of the vast central orb, whose blessed influence gives them stability, and from whose exhaustless warmth they inherit vitality and nourishment.

The march of civilization has crossed the Rocky Mountains and the Sierra Nevada. Its vanward hosts now pause upon the glittering sands of the Pacific. You have ceased to be the Great West. Population, wealth and political power now preponderate in the Valley of the Mississippi. This valley is now the great center. From this day forth and forever, you and your descendents can dictate the laws and policy of this government; aye, of this continent, if you will. You have the numbers, the intelligence and the energy to insure its accomplishment. You have but to combine your strength as you are now doing, and say to your servants at Washington, "these obstructions which lessen the value and mar the beauty of these great national highways, which are a reproach to humanity and a disgrace to this Republic, MUST be removed;" and your voice echoing the will of an impatient and indignant people, will command obedience.

It is time that the representatives of the people of this valley in Congress, established a national policy—a policy which looks to the heart and body of the nation, and not alone to its borders. Improvements on the seaboard are proper and right; they facilitate the arrival and departure of our foreign commerce. But is not the internal commerce of the nation as worthy of being protected and facilitated? Is it just that everything should be done for the seacoast and nothing for the interior? Is not life as precious and property as sacred in the one as upon the other? Are not the taxes with which those lighthouses and breakwaters are built drawn from the interior as well as from the border? Not a dollar should be voted by the representatives of this valley for any public works either on the borders of this Republic, or anywhere else, while these great rivers remain neglected.

There is no obligation more imperative, no higher duty can devolve upon the statesman and law-giver than to strengthen the bonds of our Federal Union. In no way can this be done so effectually as by aiding and encouraging commerce between the States, and by facilitating the intercourse of their citizens. The moderation and justice of the laws which govern a country exert an influence less powerful to preserve its unity than that which is exerted by its natural and artificial channels of social and commercial intercourse. The want of such channels may prevent the neutralizing and harmonizing of those social and material effects of climate without which a homogeneous character in the nation cannot be created; and without such character a union cannot be sustained except by force. The absence of such facilities may make the very equality of the law a tyranny in

one section of the country, while in the other it would impose no burden.

Formerly constitutional objections were urged against the improvement of these rivers by those who had no scruples in voting for seaboard works. But such objectors are now rare, and their mischievous quibbles are generally rejected by a loyal people. The wise and patriotic framers of the constitution intended its blessings and burdens to be enjoyed and shared alike by all in equal and just proportion. They never designed that it should shed a ray more genial upon the ocean's margin than that which penetrates the heart of the commonwealth. Must we be told at this time, in answer to our just demands, that there is a doubt existing as to the power of the general government under the constitution to improve these rivers, when in the last five years it has built railroads, dug canals, dammed the Red river, and pulled out obstructions from streams and harbors, expending tens of millions of the public treasure? Does any statesman gainsay its right to do it then? Does any patriot question its power to do it when the Union was in peril? When the necessity occurred there was a power in the government somewhere to provide for it. This power did not exist in the necessity. It must have existed in the constitution, for its use cannot be justified, even by the immortal Lincoln, unless it is in the letter or spirit of that instrument. Existing there, and being used to save the Union, surely the same power may be invoked to preserve and perpetuate it; to promote its harmony and increase its blessings. If a doubt exists as to this power, in God's name give the benefit of the doubt in favor of that Union to save which we have lavished the wealth of the nation, and given the precious lives of her people.

If those improvements can be justified because the Republic was in peril, certainly a wise and precautionary policy will justify all reasonable expenditure requisite to provide for its future safety by the removal of obstructions that have cost the government in the last five years, by losses, delays and exorbitant freightage, much more than would exterminate them forever. The importance of safe and rapid water transportation through the Valley of the Mississippi, in every direction, commends itself to the favor of the prudent and sagacious statesman as a great measure of public safety, not only because of the immense facilities which it affords for the rapid concentration of troops towards any threatened point, but also because of the ease with which the wants of our armies can be supplied from this grand central granary of the country. Here too, on these rivers, in the very heart of the nation, secure from all possible approach of her foes, she can construct and send forth to the ocean her unconquerable navies to protect her commerce, to defend her coasts, and to shed over the future pages of her history the same re-

fulgent glory that beams so brightly on the past records of the American people.

Who in his wisdom or prescience can say where it may next be necessary for this people to hurl the might of their military and naval power; or when the evil day will come again? Must we remain supinely awaiting its coming with all the lessons of experience wasted upon us, the government and the community annually losing more than the total cost of improvements, demanded not less by humanity than by common sense, required no less by political prudence than by commercial necessity, and yet complacently arrogate to ourselves the title of being the most enlightened people on the face of the earth? As though man or State could win and wear unchallenged, the seal of greatness without achievements commensurate with the title.

England is to-day and has been for years past expending millions in the construction of eight hundred miles of canals among the jungles of India to improve the navigation of the Ganges. Austria, whom we are wont to consider one of the most enlightened nations in Europe, has expended more in the improvement of the Danube alone, since the introduction of steam, than we have upon this great stream and all its tributaries together.

Our law-makers cannot be ignorant of the fact that every additional facility created for the safe and rapid transportation of the armies of the Republic brings with it a corresponding increase in the effective power of its forces, and a decrease in losses and freightage; thus doubly compensating the government for its care and foresight. The benefit of this wise policy does not, however, end here; for it enables the government to shed the blessing of safety over those who are upon such highways, and to create a reduction in the cost of transportation to the people that is felt throughout the length and breadth of the whole country. Thus the purposes of war and of peace are both accomplished at the same time, and with the same expenditure.

For the very laudable purpose of constructing railways from the Mississippi to the Pacific slope, large subsidies have been granted. For the one from Lake Superior to Puget's Sound we have given 47,000,000 of acres of the public domain. This land, at $1.25 per acre amounts to nearly $60,000,000; enough to improve the navigation of thirty thousand miles of these rivers twice over. It is within the bounds of reason to assert that these thirty thousand miles of rivers thus improved could accommodate one thousand fold more of the products of the country in transit than this 1,800 miles of railway when completed, and at much cheaper rates. When the railroad is built, it must be renewed from time to time. The track must all be relaid within a few years, at great cost, and the road-bed and

bridges will need constant repairs. The improvement of the rivers once accomplished, remains forever a grand and imperishable monument of the genius, the intelligence and the patriotism of the present generation.

It is claimed, and I think with reason, that the government will receive full compensation for these grants by the enhanced value of the lands it retains near these roads. We see how rapidly they are sold as the roads are constructed. The government owns about 400,000,000 of acres drained by these rivers. Their improvement would greatly enhance the value of these lands by making them more accessible to the chief marts of the country. We may safely assume that these improvements would expedite their sale at least five years. Their value at $1.25 per acre is $500,000,000; and if this assumption be correct, the government would save five years' interest on that amount, which would be about $120,000,000 over and above the cost of the entire improvement. If they were sold one year earlier in consequence of these improvements, the government would save as much in interest as the total cost of the work. A tax of one cent per acre per annum on these lands would pay for the whole cost of these improvements in five or six years.

It is not unusual for our best steamers to pay an insurance of twelve per centum per annum on the Mississippi. On the Missouri, Arkansas, and Red river, the rate is much higher. The commerce in transit pays a corresponding rate. This commerce was estimated twelve years ago, in Col. S. H. Long's report to the War Department, at nearly twelve hundred millions of dollars annually. One per cent insurance on this immense commerce would be twelve millions of dollars per annum. I have no means of ascertaining the exact amount now paid, but have no doubt that this is less than the reality. Yet this enormous tax of $12,000,000 does not represent the fourth part of what the country is annually losing by these obstructions. It only represents the absolute annihilation of that much of the created wealth of the people that is destroyed year after year. It exhibits no portion of the uninsured property annually lost, and none of the still more enormous losses incurred by vexatious delays and exorbitant freightage, all of which must be borne by the consumers and producers of this vast commerce. The patient and long-suffering consumers and producers—they who are the sovereign people, " the salt of the earth," claiming to be the most enlightened and intelligent people on the face of the globe, and yet are foolishly, yea sinfully, losing this fifty or sixty millions of their own wealth year after year—losing twice as much as the total cost of removing the evil, every year, simply because they do not, as they should do, command their servants at Washington to stop this criminal waste at once, and save the blush of shame from mantling the cheek of every thoughtful and intelligent American.

If this government were not a government of the people, made by themselves and for their sole benefit, there might be some reason for this disgraceful neglect. If we were compelled to await the mandate of some imbecile tyrant, impiously claiming to rule us by divine right, we might stand acquitted of this shameful dereliction; but in a land where the will of the people is the supreme law—in a land where they read and reflect—a land where the light of knowledge pervades the whole realm, like the blessed rays of the sun, and glows as brightly in the humblest cottage as it does in the palatial mansion—we should need no other impulse than the spirit of the age and our national pride to urge us to the consummation of this noble enterprise.

I will not at this time occupy the attention of the convention with a description of the different classes of obstructions which interrupt the navigation of these rivers. It is sufficient for the present to state that similar obstructions have been removed elsewhere. Indeed, there is scarcely a river in the whole valley, large enough on which to manœuvre a steamboat, that cannot be made absolutely safe and navigable. From my own knowledge of these obstructions, I feel fully warranted in asserting that there is not one of them in any of these rivers, great or small, that engineering skill and cunning cannot master. The human intellect, that mysterious light from the infinite wisdom of God himself, that has revealed to man the curious secrets of nature, taught him to time the flight, and weigh as with a balance the ponderous spheres that move in the immense void of space, given him dominion over the elements, and harnessed the very lightnings of heaven to bear his inspirations to the extremest limits of land or sea, is competent to curb and direct those mighty currents, to banish from their hidden depths their dreadful terrors, and make their vast waters the faithful and submissive servants of his will.

In conclusion, Mr. President and gentlemen of the convention, I thank you in behalf of the Merchants' Exchange for the patient attention you have given their humble spokesman. The theme is as exhaustless as the river itself, and worthy of the highest eloquence and the gravest consideration of your ablest statesmen. The presence of so many of the earnest men of the country, counseling together upon it, assures me that the improvement of these waters is already decreed. This grand and imposing concentration of mental force and energy, drawn hither from all parts of the valley, is an eloquent illustration of that giant stream which has, for some wise purpose, been given into the sole guardianship of this people. Its restless waves are borne to our shores by southern breezes that have danced along its surface for thirteen hundred miles. Its wealth of waters are swelled by pine-clad hills whose northern slopes send their sparkling rivulets to the Arctic seas. The Appalachian chain pours forth its stores to swell its power, and mingled in its vast volume are the crystal floods that have brightened the jewelled sands of the

Rocky Mountains. You come to us from homes as distant and as various as the sources of that mighty river, representing the wealth, the intellect, and the energy of this empire valley of the continent. And when the united force of your wisdom and your will is felt in the Capitol of the Republic—as, thank God, it soon will be—it will give an impulse and power to this movement that will be as resistless as the old Father of Waters when he gathers his annual floods, and moves in overwhelming grandeur to the ocean.

REMARKS,

Made at the First Alumni Banquet of Washington University, St. Louis, February 22, 1868.

Mr. President:—I trust that I shall always be capable of appreciating every sentiment that may be uttered in behalf of labor and education—the two great motors that are constantly advancing the cause of human progress, and extending the blessings of civilization. It is a sad reflection to think that there are so many young men of the present day who are reared in the belief that labor and respectability are incompatible. The parent or teacher who inculcates, or fails to eradicate, this pernicious idea, has a grave responsibility resting upon him. Toil is the foe of vice, and I am sometimes tempted to believe that it is more powerful in preventing wickedness than religion itself. Honesty, sir, is the favorite companion of labor, whilst health, happiness and independence are rarely absent from its pathway. You have most properly associated knowledge with labor, in the sentiment just read. It is the intellect alone that elevates and ennobles labor. Guided by knowledge, exertion and triumph are synonymous. Directed by her teachings and aided by her patient research, we exercise our own powers judiciously, and have the mighty forces of nature placed at our command, more faithful, obedient and powerful to serve our purposes than the slaves of the most absolute monarch in the world.

When our Heavenly Father imposed upon man the penalty of earning his bread by the sweat of his brow, "justice was tempered with mercy;" nay, more, it was clothed with loving-kindness. To this

creature of sin, henceforth to be exposed to the temptations of wickedness, labor was given as the shield beneath whose protecting shelter could cluster and flourish about his hearthstone all of the domestic virtues, such as love, truth, gentleness, and chastity, and, enveloping it with an atmosphere purer than that of Eden itself, win him back to heaven by making the home of the toiler what the Almighty intended it should be—a sweeter paradise than that from whence he was expelled.

REMARKS,

Made at a General Meeting of Members of the Merchants' Exchange and Citizens of St. Louis, February 16. 1870, to Take Action in Relation to the Death of John J. Roe.

Mr. President:—More than a quarter of a century has passed since I first became acquainted with him whose sudden death has cast upon our city this mantle of gloom. Through that long period I have witnessed much of that untiring industry and indomitable energy which characterized him; but it is only within the past few years that I have had the honor of being intimately associated with Captain John J. Roe in several important enterprises. Only for a few brief years have I enjoyed the rare good fortune of having him as one of my nearest and most intimate neighbors, and one of my truest and most cherished friends. For more than three years past I have sat almost daily by his side in the directory of the largest bank; and, whilst receiving instruction through his counsels and experience, I learned to admire, I might say to wonder at, the rare judgment, brilliant business qualifications, and liberal ideas with which he was endowed. Within a few brief hours I left that board surrounded with his accustomed associates still bowed down in sadness for his death, and my poor words can but feebly tell you, sir, how highly they honored him living, and how deeply they mourn him dead. Alas! not by them alone will his able counsels be missed, for when we turn to the many other important public and private enterprises that were confided either partially or wholly to his guidance, we feel how irreparable is our loss. His sagacity, nerve and public spirit prompted him to extend a helping hand to

almost every worthy movement of the day, and when that hand was given, it seemed as though its magic touch insured success. The iron bands which stretch out to the fertile plains of Kansas and Iowa, and bring to your doors the rich products of the West and North, owe their extension and completion, in great part, to the material aid and judicious action of him who now lies cold in death. When the few enterprising men striving to span your majestic river with a bridge, felt that the darkest hours of the undertaking were upon them—when they thought disaster and defeat were close at hand—they sought the aid of him whose cheerful voice will be heard amongst them no more forever. Their appeal was not in vain. His aid came, not in meager pittance, but in the form of a pledge to pay towards its construction one hundred thousand dollars in cash; whilst the very fact that the enterprise was approved by his judgment was worth to it a half-million more. In the management and control of these three great public institutions, the National Bank of the State of Missouri, the North Missouri Railway, and the bridge, in each of which he was so largely interested, his clear head and generous heart can never be replaced. The gentleness and simplicity of childhood still lingered upon the matured man to the hour of his death, and shed their charms upon his manners, and gave freshness and tone to feelings and thoughts which sixty years failed to crystallize into the coldness of indifference. The kindness of his heart could not be kept hidden even in the ordinary transactions of business. It might be likened to the particles of pure ductile gold which we see sometimes sparkling through a seemingly inflexible mass of quartz, to encourage effort and to reward toil. Even so did the exuberance of his charity and goodness seem continually to manifest itself in the daily avocations of his life, and win for him the love and gratitude of all. I have often thought, when reflecting upon the high social position of our deceased friend, and upon his early trials and privations, that he was one of those examples purposely designed by our Creator to encourage the humble and sustain the unfortunate through the battle of life. For this reason, as well as because of his many virtues, it is eminently proper that we thus publicly perform these sad offices of death. Not until I was robbed of his presence forever, was I conscious of the great depth of my affection for him; and, although I know it is a blessed privilege for me to be permitted to mingle my grief with yours, and with the multitude of his friends about me, yet it would be more in consonance with my feelings to manifest my sorrow by that silence which the precincts of the grave impress upon us all. It was my intention, before closing my remarks, to refer to one spot in which, of all others on earth, the loveliness of the character of John J. Roe was pre-eminently displayed. I dare not, however, trust myself, Mr. President, to speak of that home which has been made so desolate by the inscrutable will of our Heavenly Father.

REMARKS

MADE TO THE ST. LOUIS COUNTY COURT, OCTOBER 21, 1870, IN RELATION TO A STATUE OF EDWARD BATES, PROPOSED TO BE ERECTED, AND WHICH WAS SUBSEQUENTLY PLACED IN FOREST PARK.

I beg the indulgence of the court for a few minutes, to present for its consideration a matter in which I and the distinguished citizens now present with me in this honorable court feel a deep personal interest. They are, as the court doubtless knows, almost constantly occupied with their various pursuits; and it will be exceedingly inconvenient, if not difficult, to have them all again present before you. I trust, therefore, they may be permitted by the court to lay before it, without the postponement suggested, the business which has called them before you.

Intelligent nations, from the remotest times to the present day, have recognized the importance of encouraging the practice of virtue and the development of mental power, by the erection of lasting memorials in honor of those whose lives have been devoted to the public good. By such means a country not only testifies its gratitude, but evinces its wisdom. The young are in this way taught to respect talent, to admire genius and to honor noble deeds; and they are thus silently but powerfully stimulated to win for themselves that lasting approbation of their fellow-men which is achieved only by the highest development and proper use of the faculties we possess.

In any court within the limits of the city of his residence—I might almost say in any circle within the limits of the republic—it would be needless for me to publish the virtues and abilities of Edward Bates. While he lived his praises were breathed on every tongue; even those who ventured to differ with him in opinion during a contest the most momentous in its results which the history of the world records, and in which the passions of men were roused to the highest possible pitch, none dared to doubt the sincerity or to question the courage and patriotism of the earnest coadjutor and confidential adviser of Abraham Lincoln.

The statesmanship which was trusted by the President, the eloquence which fascinated while it convinced, the erudition and force which marked his writings, and the purity of character which surrounded this great and good man, while living, with an atmosphere almost heavenly, are known and acknowledged throughout this whole land.

We come, therefore, to petition you in behalf of the people of St. Louis County to permit them, through your action, to unite with us and other private friends and admirers of the deceased statesman and jurist, in erecting a memorial tribute of imperishable bronze to perpetuate his fame, to aid us in adorning some prominent spot in our city with a superb work of art that shall stand as an evidence of the gratitude of this people for his public services, a proof of their high appreciation of the purity of his private live, and a silent and impressive appeal to the youth of this and succeeding generations, to emulate the excellence and equal the good deeds of Edward Bates.

REMARKS

MADE AT THE CELEBRATION OF THE COMPLETION OF THE RAILROAD BRIDGE OVER THE MISSOURI RIVER AT THE CITY OF ST. CHARLES, 1871.

Gentlemen:—My honorable predecessor, who is so modest as to assure you that he has been simply ornamental and not useful in his office of President of this company, has just told you that there are many gentlemen yet waiting for something to eat, and they cannot of course get it if I respond to your complimentary call. I trust you will therefore excuse me, for I have been kept so long hungry myself that I can sympathize with them. [Cries of "That won't do;" "Go on, go on."] Well, gentlemen, there is another reason why I don't think I ought to make a speech, and that is because you will expect me to talk "bridge" to you; and being prominently identified myself with a work similar to this, it does not seem becoming in me to express that admiration for Colonel Smith's success which I honestly feel, or that praise which I really think he deserves for accomplishing what I am striving to do. The very fact, however, that I am thus engaged, makes me more competent, probably, than many others present, to judge correctly of his real merits in surmounting the great and novel difficulties that he has encountered, and which he has so triumphantly overcome.

My experience with this great stream has taught me that in all conflicts with it, "eternal vigilance is the price of safety." Constant

watchfulness is one of the chief requisites to insure success. Knowledge and judgment are scarcely less necessary. In its freaks and caprices the river is seemingly as inconsistent as the most fickle of the fairer sex.

It apparently sets at nought the most approved theories, and overrides the most scientifically devised schemes for its conquest. To the superficial observer its ways are shrouded in an obscurity scarcely less mysterious than that which clothes the unexplored recesses of its mountain rills. Yet no grain of sand, be it ever so mall, is borne onward through its devious channels to the sea, but obeys some law more fixed and unchangeable than any in the code of the Medes and Persians. No giant tree standing in solemn grandeur on its banks is made to bow its stately head beneath those dark waves and sweep onward to the Gulf, but does so in obedience to some one or more of those immutable rules which God in His goodness and wisdom has instituted for the governance of matter at rest and in motion. These ordinances of the Creator this young engineer was compelled to comprehend and master before he could safely dare to attempt the planting of those stately piers where we see them now, in the very channel of this mighty river. Once assured, through patient study, careful experiment and close observation, that he was properly applying these divine laws to accomplish his ends, he rested his hopes of success on their unfailing truth, with a faith scarcely less reliant than does the Christian for his eternal salvation upon the atoning blood of the Savior. The dangerous pranks and fantastic whims of the stream were to him, when familiar with the edicts which our Heavenly Father instituted to control it, as readily comprehended and as easily accounted for as the simplest phenomena in every day life. Guided by the light of science thus obtained, its vagaries were anticipated and provided for by him with as little ostentation and as thoughtful providence as one takes up his umbrella on a cloudy day or secures his fuel before the coming of the frost. No half way knowledge of the laws which control this ceaseless tide, or those which regulate the statical conditions of matter, the strength of materials, effects of temperature, and the like, would have sufficed to rest this beautiful structure upon its solid foundation far beneath the sandy bottom of the river, or to stretch across its turbulent basin like gossamer threads that strong and graceful network of iron over which the commerce of mighty States will be henceforth borne in speed and safety.

From my very heart I congratulate Colonel Smith for this grand triumph of engineering skill. The profession has much to thank him for. His experience here will be of great value to it, and I trust it will soon be published. I feel doubly pleased to offer my hearty congratulations to him, for I believe our worthy President and all of my brother Directors will bear me witness that my strong faith in

the ability of our engineer never faltered during the darkest moments, from the inception of the enterprise to the present time. It therefore gives me double pleasure to tender my congratulations to him on the completion of a work of which he may well be proud, and which gives me the wished for proof that my faith in his skill, judgment and ingenuity has been most signally justified.

INAUGURAL ADDRESS

Before the St. Louis Academy of Science, as its President, January 15, 1872.

Gentlemen of the Academy of Science:—

The charter of your association, granted fourteen years ago, contemplates the creation of an institution in St. Louis for "the advancement of science and the establishment of a museum and library for the illustration and study of its various branches." Through the labors and influence of several of the scientific gentlemen first enrolled among its members, aided by the liberality of older kindred societies and private individuals in America and Europe, the institution thus created grew apace during the earlier years of its existence, and accumulated many valuable records and scientific works, which formed the nucleus of what would have grown to be by this time a valuable library. Liberal donations of objects of interest in great variety, illustrating many of the most important departments of science, flowed in from private citizens and corporations, both at home and abroad, with such generous profusion that its museum began to be one of the most attractive features of our city. After a few years of such encouraging prosperity, the building in which the library and museum of the Academy were contained, on Myrtle street, near Seventh, was unfortunately destroyed by fire, and these valuable collections perished in the flames.* This misfortune, coupled with the knowledge that the loss was not even covered by insurance, together with the fact that the still more sad and desolating calamity of civil war had just swept

* The entire library and a small portion of the cabinet only were saved.

through the land, cast such discouragement upon its members that for several years little effort was made to restore its prosperity. The rapid increase of membership and the lively interest which have recently marked the history of the Academy give, however, good reason for its friends to hope that it will soon rank among the most useful, attractive and creditable institutions in the country.

Your constitution declares that the Academy shall embrace the departments of Zoology, Botany, Geology, Mineralogy, Palæontology, Entomology, Chemistry, Physics, Mathematics, Meteorology, Comparative Anatomy, and Physiology. By the liberal provisions of your charter, the scope of your investigations may be extended to such other branches of science as the members controlling the institution may deem proper.

It will be seen, therefore, that the fields from whence are to be culled the treasures with which your records and museum are to be enriched, may really embrace the entire universe.

The majority of mankind, even of those possessing more than mediocrity of intellect, are so constantly occupied with the daily industrial and commercial pursuits of life that they know but little of what science is accomplishing at the present day. They are still less aware of the great aggregate of patient labor that has been performed by those who have chiefly contribuied to her advancement; and I regret to add that they have but a faint idea of the immense benefits that flow to the human race as a result of scientific investigation and discovery.

Could a correct appreciation of the great mental improvement and physical amelioration that have come to man through the aid of science be but once established in the popular mind, your Academy would not lack public encouragement. The greatest interest in its success would be felt by our people at home, for it would be recognized as one of the most certain means of elevating and improving the condition of the human race.

There exists no reason, save that which is to be found in the indifference of our own citizens, why an institution like this, created for the diffusion of useful scientific knowledge among men, and located in the midst of a region of unparalleled resources, and rich in the promise of future greatness beyond any example of the past, cannot be built up to an eminence equaling, if not surpassing, that of any similar institution in Europe. It numbers already among its members men of science, whose contributions to its published records have awakened profound attention, and elicited the most respectful comments from foreign academies; and whose talents and learning are acknowledged in the most enlightened circles of Christendom. These gentlemen and other members equally zealous, but less known perhaps to fame, would, if encouraged, cheerfully devote much of their time in communicating to the scientific world at large the results of

their own valuable experience and investigations; and would likewise aid in arranging and collating the scientific data that would be promptly furnished in return by men eminent in science in other parts of the world. In this manner, here in our midst, the results of scientific inquiry everywhere might be continually unfolded, and its discoveries could be, from time to time, presented in simple and charming vesture to those whom it should be the aim of all governments to improve and elevate; those who are daily toiling in the development of the material interests of the nation, and who constitute the nation's reliance in her hours of trial—the working classes of the country. It should be one of the chief purposes of government to encourage, in every judicious manner, the dissemination of such scientific facts among this, the largest portion of our population, as will give them a general knowledge of the principles involved in the physical development of the human race, the preservation of health, the nature of disease, the peculiar qualities and composition of the natural elements with which they are surrounded, and, in a word, to supply them with whatever important truths science can impart of value in the preservation of life, the promotion of happiness, and the attainment of the highest perfection in the various departments of human industry.

Unless the immutable laws which regulate existence be understood, they cannot be intelligently obeyed in the preservation of health; nor can they be advantageously applied in accomplishing the purposes of life. One of the grand objects for which the human mind seems specially designed is to comprehend the sublime phenomena with which it has been surrounded; hence all wise governments should encourage such institutions as are particularly designed to accomplish this purpose.

The wonders that are presented by science for the contemplation of men are frequently so startling as to be deemed by the mass of mankind only the idle fancies of those who first bring them to our notice. Science, however, only recognizes those theories as established truths when every one of the particular phenomena to which the theory is applicable can be satisfactorily explained by it, and by no other. It is only by keen observation and thoughtful study of the phases of nature that science advances. The recorded knowledge of those who have gone before must be carefully examined and compared with the experience and observation of the present. Even then, years of seemingly unrewarded labor, in almost impenetrable darkness, sometimes ensue; but such stores of facts are at last accumulated that she suddenly ushers us into the glorious presence of a new-born day. In its pure light the mists which hung over over our vision melt away, and we see revealed some grand law of nature hitherto unrecognized. Such, for instance, was the law of gravitation, discovered by Sir Isaac Newton, and by which the movements of the heavenly spheres are explained to us. The development of the theory of the conservation

of matter, and the correlation of forces, is another illustration of the discovery of, perhaps, a still grander truth—one which Faraday pronounces "the highest law in physical science which our faculties permit us to perceive."

Indeed, some of the results of scientific inquiry have been so amazing that the powers of the human mind seem almost elevated by them to the verge of omnipotent wisdom.

The discoveries in astronomy are especially calculated to raise our conceptions of the power of man's intellect to a degree that is well-nigh impious. Fortunately, however, for our humility, that department of science, more perhaps than all others, is best calculated also to elevate to the highest possible point our ideas of the power and wisdom of the Creator. What grander illustration, for example, of the wonderful power of intellect can be imagined than that exhibited in the discovery of the planet Neptune?

Studying the perturbations of the planet Uranus in its orbit, two eminent mathemeticians, Leverrier and Adams, were led, each unknown to the other, to investigate their cause. They knew that the attraction of gravitation could alone account for these irregularities, and they believed the inducing force was an unknown planet. They had nothing but the eccentric orbit of Uranus and its mass as the data by which to find the orbit, and the place in that orbit of the disturbing body. Yet before that unknown world, ninety-four times greater in bulk than this earth, had been recognized by human eye, the equations of Leverrier enabled him to track its majestic sweep around the distant verge of planetary space with such unerring certainty, that he was enabled to indicate almost the exact place in the firmament in which it was to be discovered. He wrote to Galle, in Berlin, that at that date it could be found in a certain part of the heavens. The very first night after his friend received this letter, he turned the telescope in the observatory of Berlin as directed by Leverrier, and the mighty planet stood triumphantly revealed, within a single degree of the place indicated.

Sometimes scientific discovery pauses in apparent hopelessness in certain fields for centuries; in others it advances in slow but constant pace, each step being due to the successive or united labors of many minds; whilst in others, again, it moves onward with strides so rapid and startling as to challenge the admiration of the world. Some of the phenomena of electricity and magnetism were known for ages, before any forward step was made to unravel their mysteries. In the investigation of the laws of light and heat it has, in these later years, made marvelous advances.

Some of the recent discoveries in this field are so wonderful, and at the same time so beautiful, that I feel tempted to explain a few of them this evening, very briefly, however, for the benefit of those of

our members who may not have had time to become acquainted with them.

Newton discovered that when a beam of light was passed through a denser medium than the air it was refracted, or bent, in its passage through the denser medium, out of a direct line. When the beam was passed through a glass prism, he discovered that some of its rays were bent more than others, and thus became separated beyond the prism, and that when thus separated these rays were of different colors, and when thrown upon a screen the colors were ranged in the order in which we see them in the rainbow.

The colors thus produced by the dispersion or separation of the rays of a beam of sunlight, are usually known by the name of "The Solar Spectrum."

Newton found, also, that by passing these colored rays back through another prism, suitably placed, they became combined again, and then appeared, as before, in a single beam of white or colorless light.

In this alternate analysis and synthesis of light did Newton ponder. He had made the first great step in the investigation of its marvelous phenomena, but even his giant intellect could advance no further in solving its mysteries.

The anatomy of the silken tresses which grace the brow of a rustic maiden are to her no more mysterious than were those pencils of light to the mind of Newton. She may spread out her flowing wealth in the sunshine and wonder at its lustrous beauty, but she can no more number each one of its single fibres than could Newton count the threads which came to him in that beam from the distant orb of day. To her the mystery of its growth, the cunning workmanship of its roots, the delicate architecture of its fairy-like chambers, and the pristine fluid that for a few brief years will circulate within its tiny channels and keep the snow-flakes of age from dimming its raven sheen, are no less unknown than were the scores of fascinating truths we now possess respecting light, unknown to that great philosopher. Yet this was the first grand step toward those wonders which have culminated within the last twelve years in the astonishing revelations of the spectroscope.

Subsequent philosophers, investigating the solar spectrum thus spread out by Newton, discovered that when the thermometer was exposed in the variously colored rays in succession, from the violet to the red, the mercury arose gradually and attained its greatest height within the red rays. Continuing still further with it in that direction, the remarkable discovery was made that the mercury rose much more rapidly beyond the red, where no color whatever was visible. Thus was the curious fact discovered, that the sun emitted certain rays incapable of exciting vision, yet possessing far more heating power than any of those revealed to us by sight. The temperature was then tried at the other end of the spectrum, beyond the violet,

but here there was scarcely any increase of heat to be found. On placing certain substances on this end of the spectrum, however, what was equally as startling as the existence of the obscure rays of heat beyond the red, was the discovery that there were invisible rays beyond the violet, which possessed remarkable chemical power. These are called the actinic, or chemical rays, and are those which are most valuable to the photographer.

It must be remembered that all illuminated bodies possess the power of reflecting the rays of light. By illuminated bodies are meant all white and colored objects revealed to us by sight; as it is only by the rays of light which fall upon them, being reflected from their surfaces, through the eye, upon the delicate nerve tissues of the retina, that their presence is revealed to us. All objects which do not reflect light are black. In comprehending the art of the photographer, it is important to remember these facts. Hence it matters not whether certain chemical solutions are exposed in the direct sunlight to these invisible rays, or whether these rays are reflected from the face of a human being, a house, the moon, or other illuminated object upon such solutions. Their action will work the same chemical changes. These chemical rays, reflected with the others from illuminated objects placed before the camera of the photographer, produce an atomic change upon the sensitive solutions with which his plates are prepared, and thus form upon them images of such objects as are in the field of the lens at the time.

The colored rays of the spectrum possess chemical power also; but, like their heating power, it is less than that possessed by the invisible rays.

The phenomena exhibited by the invisible heat rays at the red end of the spectrum are no less remarkable than those manifested by the chemical rays. A correct idea, however, of the cause of these phenomena, cannot be well comprehended without some knowledge of the undulatory theory of Light, now almost universally accepted as the only one by which all of its various phenomena are believed to be explained.

The analogies in the phenomena of light and sound are so numerous that a brief explanation of some of those of sound will enable us to comprehend more easily those of light. Sound and light are reflected in the same manner, the angles of incidence and reflection being equal. Sound, like light, is refracted when passing through media of different densities; each may be doubled in intensity, or destroyed, by interference; and each is propagated by the undulations or vibrations of the conducting medium.

The phenomena of heat and light are likewise so closely allied that a theory which is applicable to one will probably explain every

phenomenon of the other. Heat is reflected, refracted, transmitted and polarized in the same manner as light.

All sonorous bodies create sound by imparting their vibrations to the air when they are themselves thrown into vibration. When they vibrate in a vacuum, without contact with objects outside of the vacuum, they produce no sound, because they cannot affect the air.

Many other substances convey sound equally as well as the air, but air being the only element usually in contact with the ear, it is the natural medium for man. The metals, water, wood, and many other substances, are excellent conductors of sound.

If it were possible for us to see the particles of air when they are set in motion by a harp-string making about eleven hundred vibrations per second, we would see them spaced off in equal distances of about one foot in length, in every direction from the harp-string. In every alternate foot or space we would see them moving towards the string, and in each intermediate space we would see them moving from the string. The next instant the atoms in all these spaces would have their motions reversed. Each alternate set of atoms would be seen approaching and compressing each other, and then instantly rebounding from each other and compressing the set on the opposite side. These motions to and fro would be found to correspond exactly in time with those of the harp-string creating them. It would be seen that the impulse from the harp-string would be first imparted to the set of atoms nearest to it, and by this set it would be imparted to the next and so on out to the most distant ones in the system. Hence eleven hundred vibrations would have to be made by the string before the air eleven hundren feet distant would be set in motion. These vibrations of the air, when they fall upon the tympanum, create the sense of sound. They travel at the rate of about eleven hundren feet per second, the speed varying with the density and temperature of the air. The to and fro movement of the atoms in each of these eleven hundred spaces, or waves of air, is called the swing or vibration of the atoms. This swing is of much greater amplitude near the string, and diminishes as the vibrations are more and more distant. Hence the impulses upon the ear will be much more energetic near the string than at a distance. This note sounded will therefore be louder. It will still be the same note, however, whether the string be distant or near, because each wave created by it is of exactly the same length, and hence the waves fall in exactly the same periods. It is the rapidity of these impulses on the ear that determines the pitch of the note. If the harp-string were shorter, or if it were lighter, or if it were more tightly drawn, its vibrations would be more rapid. Then the waves would be shorter, and more of them would be required to make up eleven hundred feet in a second of time. Consequently, as the waves travel at the same

rate without regard to their size, they would come into the air more rapidly and a note of higher pitch would be the result.

The same note sounded by a rapidly approaching steam whistle on a locomotive has a higher pitch to the stationary listener before, than it has after the whistle has passed and is retreating from him. If the listener be himself on a train rapidly meeting the one on which the whistle is sounding, the change of pitch at the moment of its passing the hearer will be much more marked. The current of steam issuing from the contracted opening in the whistle is thrown into rapid vibrations by being directed against the sharp edge of a hollow metallic cylinder. These vibrations are at once imparted to the air just as they would be if made by a harp-string. If the whistle itself be moving, the sound waves will be shorter in advance of it than in its rear. The more rapidly it moves the greater will be the difference in their length; hence if it be approaching, more waves will enter the ear in a second of time than if it be retreating.

The tympanum is thrown into vibrations corresponding with those of the air, and when these fall in regular periodic succession at a rate not less than sixteen per second, nor more than thirty-eight thousand per second, they create the sensation of musical sounds. When the vibrations are irregular, the sense of noise is the result. Without stopping to explain how these vibratory motions of the tympanum are conveyed from it, by the four minute bones within the ear, to the fluid contained in the complicated organ called the labyrinth, and from thence to the nerves, I will simply refer to the wonderful little organ discovered in the laybrinth by Marchese Corti, and which Tyndall pronounces to all appearances a musical instrument similar to a lute; with three thousand microscopic fibres, stretched in such a manner that some one or other is actuated by the various vibrations within this great range of periods. These vibrations are thus taken up from the labyrinthine fluid and transmitted to the nerve filaments which traverse the labyrinth, and by these the sensations are conveyed to the brain. An ordinary lute string may be roused into vibrations by a note from the voice, or by an organ peal, when the periods of vibration of the air producing the note and the periods of vibration of the string concur. If there be discord between the note and the string, the latter cannot be roused. If you sing into an open piano, the strings in unison with the voice are thrown into vibration, but none other. A feeble note, because of its coincidence with the periods of a sonorous body, may rouse it into sound, while a far more powerful note, because of its non-concurrence, would produce in it no excitement whatever.

If two tuning-forks of exactly the same pitch be placed at considerable distance from each other in the same room, and one be struck, the other will immediately respond to it. If there be discord between them the one at rest will remain silent.

The ear is attuned to a wide range of sounds. The slightest musical tremor which falls upon it, within the range of eleven octaves, excites some delicate fibre within the ear whose periods of vibration synchronize with it; and the sense of music is thus awakened in the brain. Each one of the great multitude of wavelets sent forth from a grand orchestra finds in the delicate lute of Corti some chord in unison with it; thus the concord of sweet sounds is analyzed and each tremulous ripple in the air faithfully reported to the brain. If vibrations strike the tympanum but find no responsive chord within the ear, they are powerless to excite audition. Those less than sixteen and more than thirty-eight thousand per second find no chord in this marvelous lute attuned in harmony with them, and hence they fall upon the ear unheard.

Light and heat are transmitted by the vibrations or undulations of a fluid far more attenuated than the air or any known gas. This fluid fills the illimitable regions of space, and is known by the name of the luminiferous ether. By its wonderful tenuity it is able to pass almost without hindrance through the molecular structure of the densest substances known. To use the illustration of Thomas Young, who was chiefly instrumental in establishing the theory, "this fluid passes through the solid matter of the earth as a breeze does through a grove of trees." With our ideas of the solid and compact structure of certain bodies, it is hard to comprehend the possibility of any fluid possessing such tenuity as to enable it to pass almost instantaneously through glass, crystal, metals and stones, yet the creation of an ethereal vacuum seems an utter impossibility; while the evidence of the existence of the luminiferous ether within the most perfect atmospheric vacuum that man has yet devised, is absolutely irrefragable. Hence we must admit that the atoms of matter are not in such immediate contact as to prevent the passage of this fluid through them.

The length of the waves of light, and their periods of vibration, although so infinitely small and inconceivably rapid, have nevertheless been accurately determined. They are known to be transmitted at the rate of about one hundred and ninety thousand miles per second; or from the sun to the earth in eight minutes. The length of the waves that produce what are called the visible or colored rays has been accurately ascertained. How this can be done I have not time now to explain; but when it is remembered that the length of a wave of red light is only the $\frac{1}{39000}$ part of an inch, and of a violet wave only the $\frac{1}{57000}$ part of an inch; and that 699,000,000,000,000 of the violet waves strike the retina in a second of time, we can comprehend what a triumph of Science is exhibited in ascertaining these minute facts so positively as to be capable of indubitable proof. Four hundred and seventy-four millions of millions of the waves of red light strike the retina per second. Less than this number of heat rays

enter the eye per second, but the rapidity of their vibration is not sufficient to excite vision. The chemical rays are still more rapid, but because of their great rapidity the retina is not affected by them. They are therefore invisible to us.

When the ethereal waves fall too rapidly or too slowly upon the retina, they fail to throw the atoms of the nerve tissue into periods of vibration which coincide with them, and are, therefore, unable to excite vision, just as a powerful musical note fails to awaken into responsive vibration a tuning-fork, a harp-string or other sonorous body whose vibratory periods do not concur with it.

All waves of light and heat travel at the same speed, hence the shorter waves beat more rapidly upon the objects on which they impinge than the longer waves. It must not be supposed, however, that the ether itself is moving at this immense speed. A sea-fowl floating upon the surafce of a lake rises and falls with each wave that rolls into the shore, but the bird simply makes a slight movement to and from the shore with each wave without being borne in upon the beach. This shows that the waves are only the undulating motions of the fluid, and do not indicate the existence of a current in the fluid itself.

According as the ethereal waves break more or less rapidly on the retina, the various sensations of color are created. The waves more rapid than the red create the impression of orange; those still more rapid, of yellow; and as they increase in rapidity, the sense of green, blue, indigo, and violet are created; the violet rays being the most rapid of all that affect the retina. Thus color to the eye is what pitch in music is to the ear. Hence color may justly be termed the music of the spheres. The red corresponds with the low musical notes and the violet with the higher ones.

The ear, though less sensitive, is however, far more comprehensive in its range than the eye, the eye being limited to a single octave of wavelets, whilst the ear embraces eleven. Each octave is produced by double the number of the waves of the octave below it.

The ultimate particles of matter do not seem to be so closely compacted, even in the densest metals, as to prevent a freedom of movement among themselves to such an extent as to admit of a vibratory or molecular motion. This motion reveals itself to us by the sense of heat. Heat is simply *molecular motion*.

If we imagine an atom of matter surrounded by other atoms, yet not so closely as to prevent a certain degree of movement, and the first atom have motion imparted to it, it will, if perfectly elastic, rebound when it has reched the limit of its motion in one direction; and then, if it were not retarded by friction, the luminiferous ether, or some other influence, it would rebound with undiminished force in the opposite direction, and thus repeat its vibrations forever.

A tuning-fork makes a definite number of vibrations in a given

time, whether the vibrations be of great or small amplitude, and we have good reason to believe that the vibratory swing of an atom of matter always requires a certain period of time also for its movement, whether the extent of vibration be great or small. This amplitude of vibration may vary very greatly however. When the hand is laid on iron, if the amplitude of the vibrations be small, the piece will appear cold. If the amplitude be great, it will appear hot, and it will then impart to the ether in contact with it, and to the atoms of the hand, a motion corresponding with its own periods of vibration. This vibratory motion of the atoms, or molecules of matter, is revealed to us by the sense of heat, either by direct contact with the substance, or by the impinging upon our bodies of the ethereal waves which are set in motion by the heated body. Therefore, when we approach an object whose atoms are in more violent vibration than our own, we experience an increased sense of warmth, caused by the atoms of our body having an increased degree of motion imparted to them from the increased amplitude of the vibrations of the ether.

When the amplitude of the vibrations becomes so excessive as to overcome the attractive force by which the atoms are held together in the solid form, the substance assumes the liquid state. If the motions of the particles be still more highly agitated, the fluid will assume the gaseous form.

This vibratory motion is simply so much *force* imparted by the hotter body to the ether, the air, or other cooler body in contact with it, and unless the excessive motion in the warmer body be kept up by some other force, its vibrations gradually subside to that condition which corresponds with the temperature of the adjacent or surrounding bodies. When it falls below that, from any cause, the vibratory motion of its particles will receive additional motion from the vibratory atoms of the adjacent ones.

That molecular motion or heat is simply a form of *force*, may be proved by causing the warmth in the hand to be converted into mechanical effect or visible motion.

For instance, if the hand be held near the bulb of a thermometer, the force or heat radiating from it will cause the mercury to rise. Or this force, stored in the hand as heat, may be converted into another form of force, and this still into another kind, and this latter form, being equally invisible, may be made to produce a visible mechanical effect. Thus, if the hand be held near a thermoelectric pile, the heat discharged by the hand will be converted into electricity; this will in turn induce still another form of force, magnetism, and this will cause the needle connected with the pile to be deflected, and so produce visible dynamic force or motion.

To our countryman, Benjamin Thompson, better known as Count Rumford, belongs the credit of first proving that heat is simply mo-

lecular motion. This he did by boiling water with the heat developed by the friction of a blunt or dull drill, made to revolve by horse-power in a brass cannon which he was boring out, the cannon and drill being immersed in a vessel containing the water. Finding that he could continue to create the heat as long as he kept up the friction of the drill, and that neither the drill nor the brass was consumed in the operation, he rightly assumed that "anything which any insulated body or system of bodies can continue to furnish without limitation, cannot possibly be a material substance." Thus the theory of caloric, as taught in the early part of this century, was overthrown. Heat, or, as it was then termed, coloric, was supposed to be a highly attenuated, mobile and imponderable fluid contained within other matter, or attracted by other matter, and capable of being extracted or given off by such matter, just as moisture is absorbed by, or evaporated from, a piece of sand-stone.

The friction of Rumford's drill excited in a high degree the molecular motion of the two metals, and this motion was manifested as heat, and by it the water was boiled. The force developed by the horse might at first be deemed the primary one which produced the heat in the cannon, but a little reflection would lead us to see that quite as much water could be boiled by the direct combustion of the provender consumed by the horse during his labor, if this food had been judiciously burned under the water. We must therefore consider the sun as the prime motor, for the provender was simply the result of the energy of the sun's rays, by which the constituents of the hay or grain, the carbon, hydrogen, and the alkaline earths, were converted into vegetable forms suitable for the wants of Rumford's horse.

Although in the manifestation of heat many millions of millions of these atomic vibrations of matter occur in a second of time, science enables us with great probability, if not with absolute certainty, to estimate the rapidity of them in many substances. The phenomena attending the absorption of light by these substances proves that the periods of their vibrations concur or synchronize to a certain extent with the periods of vibration of the waves of light.

We see that the waves of sound will rouse into vibration sonorous bodies whose periods concur with those of the sound waves. Now, a moment's reflection will suffice to show that this can only be done by a loss of force on the part of the sound waves. Let us imagine, for example, the waves of sound of a certain rate of vibration directed against an intercepting screen composed of a great mass of harp-strings, all of the same pitch. If these were in accord with the sound waves they would all be at once roused into vibration. The result would be that the whole force of the sound waves would be expended on, or taken up by these strings. In such an event none of the waves would be transmitted through the screen.

Such a screen might be said then to be opaque to such a note. But to sound waves of a different rate of vibration such a screen would not be opaque; its strings would not be roused into activity; the force of the sound impulses would not be absorbed or taken up by them, and the sound would then be transmitted beyond the screen. Heat and motion are convertible terms. If these strings be thrown into motion, they become warmer than when at rest. Hence, when the screen is opaque, the force of the sound waves will increase its heat by rousing the strings into motion. If it do not intercept the sound waves it is because its strings remain at rest; they take up none of the force of the waves, and therefore they are not heated.

Suppose the various sound waves of an orchestra were directed against such a screen as I have described; a person placed beyond the screen, and protected from all waves of sound except such as passed through it, would be unable to hear the particular note to which the harp strings were attuned, whilst all the others would reach his ear.

If such a screen were composed of three or four sets of strings, each set being differently attuned, then the person so placed would fail to hear the three or four notes in accord with the different sets of strings when such notes were sounded by the orchestra.

Now let us apply this illustration to the phenomena of light.

When the waves of light fall upon a body whose periods of molecular vibration concur with them, the force of the waves is expended in increasing or sustaining the amplitude of the vibrations of the molecules of the body, just as the waves of sound would throw into vibration such harp-strings as they were in accord with, and hence an increase of heat is developed. Through such a body it is more difficult for those waves to pass whose periods coincide with these vibrations, whilst the other waves not concurring with them, would be less retarded.

This enables us to comprehend why some of the waves of light will pass through certain substances, and maintain their respective periods of vibration and consequent energy beyond them, whilst others are taken up and absorbed by the vibrations of these substances, and therefore can give no evidence of existence beyond such intercepting media.

When a beam of light falls upon a body which absorbs a portion only of those rays which excite the vision, the others which pass through will produce the effect of color. When all the rays of light play upon the retina, the sense of white or colorless light is produced. White may be produced also by several pairs of colored lights. Yellow and blue are examples of colored light which combine to produce white. Such colors are termed *complementary colors*. If, instead of blue and yellow *lights* we combine *pigments*, the result is quite different. This would produce green.

The waves of light and the obscure heat rays both pass freely through a crystal of rock-salt, the periods of its molecular vibration being such as scarcely to intercept them at all. Hence, rock-salt is said to be transparent to the rays of light and transcalescent to the rays of heat.

Clear glass is only transparent to the rays of light, while to the rays of heat it is nearly opaque. Hence, a glass screen placed in front of a fire permits the light rays to pass freely, but intercepts the heat rays. Rock-salt would not be heated sensibly by the passage of either class of rays. The obscure rays of heat arouse molecular vibrations in the screen and are absorbed, and hence persons seated beyond the screen are protected from those rays. The glass becomes heated by absorbing them, but this heat is radiated from it not only in the direction of the rays, but in all other directions, so that those behind the glass only receive a small portion of the heat which is radiated.

Ice will transmit very freely the waves of both light and heat through it; and Faraday has even exploded gun-powder in the focus of a lens of ice.

The air we breath is almost perfectly transparent to the rays of heat and light, but it is quite different with the invisible vapor of water held in suspense in the air. The heat rays are absorbed to a large extent by this vapor, while the rays of light pass freely through it. Hence, in climates favored by the sea-breeze, the air is so saturated with moisture that while the light of the sun is undimmed by it, his intense heat rays are to a large extent intercepted. At night, when the earth would rapidly radiate the heat received during the day, this vapor interposes a protecting shield again, and prevents the intensely cold nights that would result from this loss of heat. Thus, countries over which the trade winds pass have equable climates and experience but little difference in the temperature of night and day. In the elevated regions of high mountains this vapor is condensed by the cold and becomes visible to us in fogs and clouds, and finally falls in the form of mist, rain and snow. The atmosphere, when thus relieved, permits the heat rays to pass through it so freely that they attack the human form with such intensity, even amidst snow and ice in the highest altitudes, that the face and neck are soon blistered when exposed to them, although the mercury in the shade is at the time near the freezing point. Immense volumes of vapor are daily raised from the equatorial regions of the Atlantic by the action of that portion of the heat rays which are not intercepted. Hence, the air in those regions is constantly being charged with vapor as it comes from the East, deprived of it by the African continent. Being thus charged in its passage across the Atlantic, it is swept over the South American Continent by the action of the earth's rotation, and gives to the countries east of the Andes a delightful climate of great evenness of temperature, in which vegetation, protected by this

humid screen from the scorching rays of the sun, is contiuually reproducing itself in never-ending cycles of marvelous exuberance. Having reached the high and cold ridges of the Andes, the trade winds thus burdened with vapor give up their load at the eastern slopes of the mountains, and the resultant rains fill the channels of the mightiest system of rivers on the earth. On the Pacific slope of the same range of mountains the rivers are insignificant, and rains are almost unknown; whilst Africa, unblest with vapor-laden breezes to intercept the heat waves which the sun is incessantly sending forth, possesses, in the same latitude, the most terrible climate endured by man.

Iodine, bromine and lamp-black intercept the rays of light, but permit the obscure heat rays to pass freely. This quality is called *diathermancy.* A lens of rock-salt coated so thickly with smoke or carbon as to cut off every ray of light, will yet transmit the heat rays so freely as to create a high degree of temperature in its focus.

Certain substances have the power of reducing the rate of the wave periods of the luminiferous ether. Thus the chemical rays which are too rapid to excite vision, if passed through glass alloyed with uranium, are reduced in their periods so that they become visible to us as green rays. This phenomenon was demonstrated to you in the beautiful and instructive lecture of Dr. Curtman last January. When these rays fall upon certain substances, disulphate of quinine, for example, the body is made luminous. This is because the vibrations of the atoms of the quinine, being of slower periods, the rays have their periods correspondingly lessened and thus become visible. This phenomenon is called *fluorescence.*

On the other hand, the obscurc heat rays may be made visible by concentrating them through a lens upon a refractory substance; the molecular vibrations become so much increased thereby as to produce luminosity. This is called *calorescence.*

If a hollow glass lens be filled with a solution of iodine and placed in the sun, the few rays of light passing through the glass edge of the lens will converge and indicate its focus. Let the lens then be fixed and the location of the focus marked, and when this is done paste around the glass edge of the lens black paper or cloth, so that no ray of light can possibly pass through it. Within the dark shadow of this obscure lens, in its invisible focus, the heat rays will have such power that refractory metals may be raised to whiteness, fusible metals melted, and gunpowder exploded.

Perhaps one of the most marvelous facts connected with this phenomenon is, that while these ethereal billows possess such wonderful dynamic energy that their concentrated impulses can excite the atoms of metals into such violent clashing as to effect a dissolution of their compact masses, they dash harmlessly upon the far more delicate reticulations of the optic nerve, simply because their periods of

vibration do not correspond with any of those of the atoms of the nerve tissues. Dr. Tyndall concentrated the rays from an electric light by a glass lens, and in this beam he interposed, in a glass vessel, a solution of iodine and bisulphide of carbon, by which every ray of light was cut off. The heat rays, however, which constituted nine-tenths of the whole beam, passed freely through, and in the dark focus thin plates of tin and zinc were readily fused and brown paper set on fire. Into this focus he fearlessly placed his eye. The heat upon the eyelids was unbearable, and to protect them from it he cut a circular aperture through a card slightly larger than the pupil, and through this opening these powerful rays were actually thrown upon his retina without the least harm. A removal of the iodine would have permitted the concentrated rays of the electric light to have entered the pupil, and the instant destruction of the retina, by its atoms being roused into excessive vibration, would have been the result. "Nothing," says this eminent philosopher. "could more forcibly illustrate the special relationship which exists between the optic nerve and the oscillaing periods of luminous bodies. The nerve, like a musical string, responds to the periods with which it is in accordance, while it refuses to be excited by others of vastly greater energy which are not in unison with its own."

I have endeavored to give you, very briefly, an idea of the theory adopted by the most eminent men of the present day, as that which clearly explains the phenomena of light and heat. I have also tried to give you some account of a very few of the wonderful properties possessed by the invisible rays which outline each end of the prismatic colors of the solar spectrum. I will now briefly refer to some of the marvels discovered by the spectroscope in the variously tinted field comprising the visible portion of the spectrum.

Dr. Wollaston was, I believe, the first to discover that the colors were not continuous from one end of the spectrum to the other, but that the continuity of the tints was interrupted by dark vertical bands, which seemingly severed them at several places in the different colors. These dark bands soon attracted the attention of many scientific observers. Frauenhofer dovoted so much labor to the mapping of them, and to their description, that they are known as Frauenhofer's lines. In the spectrum their respective positions are invariably the same.

Let us imagine a small circular saw, laid flatwise, and having only six or eight large teeth projecting at intervals from its periphery, and upon these teeth as many prisms placed with their sides vertical and their angles corresponding with the angles of the teeth of the saw, and we will then have the chief feature in the arrangement of a spectroscope.

If a beam of light, admitted through a small vertical slit about one-sixteenth of an inch wide, be caused to fall upon the first prism in the

series, it will be bent in its passage through that prism, and its rays will be separated also in consequence of the different lengths of the various waves compassing the beam. As these fall upon the second prism they will be still more refracted or bent and still more widely dispersed.

These effects will be increased by each prism of the series through which the beam is successively passed, and in this manner the lines in the spectrum may be spread out with great distinctness for careful investigation. In this way the colors are of course ranged horizontally, and not one above the other.

By the arrangement of several prisms as described, the lines have been more accurately studied. Some of these bands are composed of several smaller bands, while others are composed of innumerable dark threads. The amount of labor expended in carefully mapping out these lines, locating them accurately upon charts and measuring their relative distances from each other, and in various other scientific observations of them, is really wonderful. Among these laborers, besides Frauenhofer, are to be named Kirchhoff, Bunsen, Angstrom, Janssen, Lockyer, and several others.

These dark interruptions in the solar spectrum were rightly believed to be caused by rays from the sun, which from some cause failed to reach the earth with an intensity equal to that of the brilliant ones revealed by the vivid colors of the spectrum,

To Kirchhoff belongs the glory of having solved the enigma of these missing rays, and in their solution science has received a power of analyzing both terrestrial and celestial matter, surpassing in delicacy of test and exceeding in amplitude of research all that the wildest dream of the imagination could have suggested.

It seems incredible that the ingenuity of man should have enabled him to perfect an instrument by which he can detect, with absolute certainty, in the slightest dust brushed from his clothes, a trace of metal so minute that one hundred and eighty millions of such particles would weigh but a single grain; and with the self-same instrument analyze with equal certainty the chemical constituents of worlds so infinitely remote in the regions of stellar space that the human mind utterly fails to conceive distances so profound.

I will endeavor to explain some of the wonderful revelations of this marvelous instrument, for which we are mainly indebted to Kirchhoff.

The spectrum of the electric light exactly resembles that of the sun, except that Frauenhofer's lines are absent from it. Incandescent metals produce continuous spectra like the electric lamp, but the *vapors* of such metals do not create continuous spectra. They simply produce one or more independent bright lines.

By so arranging a prism that a beam of sunlight was passed through its upper end, and a beam from an electric lamp through its

lower end, Kirchhoff produced the two spectra upon the same screen, the one immediately above the other; the location of the colors in both exactly coinciding. He then brought the vapor of burning sodium in the path of the electric beam, and immediately a bright yellow line was seen in the electric spectrum exactly coinciding in position with the dark D line of Frauenhofer in the solar spectrum. (This line is located between the orange and the yellow, and it has since been found to be composed of two distinct bands.)

When magnesium, iron, calcium, and several other metals, were burned separately, each one marked the electric spectrum with differently located threads of bright light, exactly corresponding in position with dark threads in the solar spectrum. Some of these threads were located in one color of the spectrum and some in others. Some of the metals produced several threads of light in two or three colors, as, for instance, iron, which has always several threads in the green and two in the violet. When the beam was passed through the vapor of several different metals at the same moment, no confusion occurred, but the lines of each metal were distinctly visible and in its appropriate place in the spectrum. This discovery established the fact that there was a direct connection between the causes which produced these threads in the solar spectrum and those which caused them to appear at the will of the experimenter in the spectrum of the electric light. But in the one they appeared as dark lines, and in the other as bright ones. Here was a discrepancy that had to be explained before it could be asserted positively that the dark D line, for instance, in the solar spectrum was produced by an incandescent sodium in the sun, just as the same bright line was caused in the electric spectrum by the vapor of burning sodium.

I explained that the waves of light are absorbed with great energy by matter whose periods of molecular vibration concur with the periods of the ethereal waves. A body, therefore, absorbs with special facility such rays as it can itself emit. If we bear in mind that the energy of the vibrations of matter generally affect only their amplitude, and not their rapidity, we will see that incandescent sodium will emit rays whose periods of vibration are the same as those emitted by the gaseous flames of sodium, and that if the rays of incandescent sodium be transmitted through sodium vapor, they must be absorbed by the vapor.

This remarkable fact was demonstrated by Kirchhoff by interposing the vapor of burning sodium in the spectrum of incandescent sodium, by which the bright D lines became at once black.

The inference is therefore unavoidable that the nucleus of the sun is composed of certain incandescent metals, some of the rays from which are absorbed by the gaseous products of the same metals surrounding the sun.

If they could come to us without being intercepted, the solar spec-

trum would appear uninterrupted by these dark lines. These absent rays are absorbed by the vapors of the different metals which emit the rays, and we have in their stead only the fainter rays emitted by these different vapors themselves. These really produce bright lines also, but they appear dark in the spectrum because of the presence of the more intensely brilliant ones which reach us without interception from the nucleus of the sun.

The fact that the rays from an incandescent metal are absorbed with great energy by the vapor of the same metal, seems to be an additional proof that the periods of vibration of the atoms of the metal, and those of the vapor are not altered in rapidity by the change from the incandescent to the vaporous form, but only in amplitude of vibration.

Roscoe tells us that the spectroscope has shown that common salt or chloride of sodium is the most widely disseminated substance known in the world. The mist raised from the agitated surface of the ocean by the winds is carried up into the aerial regions, the watery portions are soon evaporated and the infinitely minute particles of salt are left suspended in the air, and by it are borne over the most distant regions of the earth. (This action of the winds must not be confounded with the *evaporation* caused by the sun, for this does not carry up the salt.) These salt atoms seem constantly present in dust, and Roscoe asserts that a book laying for two hours on a table will collect sufficient to be detected by a spectroscope, if the dust be brushed off and burned in the light of the instrument. The one hundred and eighty millionth part of a grain thus burned will produce visibly the bright yellow D line of the spectrum!

To detect the suspected presence of a metal or earth in any substance under analysis, two separate beams are used to produce two different spectra, one being, by an arrangement of the spectroscope, shown immediately above the other. If the presence of copper, for example, is suspected in the substance to be examined, a piece of copper is burned, and a piece of the substance to be analyzed also. The vapor from each is brought into the paths of each of the beams of light at the same moment. The characteristic green lines of copper will appear at once in the one spectrum; and if copper be present, in the minutest quantity in the substance to be examined, the other spectrum will be marked with lines identically the same in color, position and number; if it be absent, these lines cannot possibly be produced. The spectra are viewed through the telescope forming part of the instrument, and by it they are magnified and are thus thrown upon the retina.

Bunsen, in 1860, having occasion to examine the alkaline earths contained in the waters of two springs at Durkheim, observed that their vapor gave certain bright lines in the spectrum never before

observed, and he at once argued that they must have been caused by the presence of some unknown metals.

Acting upon this idea, this eminent chemist evaporated forty-four tons of the water, and obtained from it two hundred grains of the new metals, Cæsium and Rubidium. Cæsium produces two beautiful blue lines in the spectrum, and Rubidium, as its name implies, two bright red ones. It is found in many vegetables, especially in tobacco, and in beets, and also in certain minerals.

More recently, Mr. Crooks, in England, discovered by the spectroscope, another new metal, Thallium. This metal produces a bright green line in the spectrum. Still another new metal, Indium, has since been similarly discovered. It produces a bright blue line.

The various gases yield, by the spectroscope, lines equally as characteristic as the metals and alkaline earths. Hydrogen, for instance, gives one line of red, another of blue, and one of indigo.

The location of the various lines of all spectra are very nearly indicated by their colors. Thus, the blue lines will appear in that part of the electric spectrum occupied by the blue color, the yellow lines in the yellow part, and so on of the others.

In the manufacture of Bessemer steel, the spectroscope is used to examine the vapors emitted by the converter in which the molten metal is being decarburized. By it the presence of various substances in combination with the iron is detected. By the Bessemer process five tons of pig iron in the converter are made into steel in twenty minutes. The carbon in the iron is completely burned out by the oxygen of the atmosphere which is driven in a blast through the molten mass. The heat thus generated is intense, but quickly subsides after the carbon is consumed, and it is of great importance that the blast be then immediately stopped. If this be delayed ten seconds the mass becomes so viscid that it cannot be poured from the converter. If the blast be stopped too soon, the metal will crumble like cast iron when it is under the hammer. The spectroscope reveals the moment when the carbon lines disappear from the spectrum, and thus furnishes an exact scientific admonition, when the quickness of vision was previously the sole dependence for success. When all of the carbon is burned out, the exact quantity requisite for the quality of steel desired is immediately returned into the converter by pouring in a certain amount of molten spiegeleisen (*specular iron*), the percentage of carbon in which is definitely known. It is necessary to burn all of the carbon out of the iron first, as it contains too much for making steel, and it is impracticable to know when exactly enough has been consumed. Hence, all must be removed so as to enable the steel maker to introduce the exact percentage required.

By the spectroscope we are enabled to declare with absolute certainty that several constituents of the sun, the planets, and the

fixed stars, are identical with those composing our earth. It has also established the fact of the gaseous constitution of the nebulæ and comets, and has supplied us with a knowledge of celestial chemistry, such as the most ardent enthusiast would scarcely have dared to anticipate. In it we have a realization of the poet's dream—

> "What skillful limner e'er would choose
> To paint the rainbow's varying hues,
> Unless to mortal it were given
> To dip his brush in dies of heaven."

With his celestial pencils charged with the glowing tints of heaven, the scientific artist now creates the perfect rainbow at his will; nay more, with skillful eye he scans its wondrous texture, and reads, amidst its blending shades, the sublime story of the constellations. Thus does Science unfold her bow of promise to mankind: one that is rich in the assurance of still grander truths ere long to be revealed.

Following step by step the sequences of cosmical phenomena, Science leads the human mind continually to the confines of that profound void within which rest the apparently insoluble problems of creation. The spectroscope, surpassing the romantic marvels of the lamp of Aladdin, illuminates her pathway within this mysterious region, and guided by its wonderful revelations, she leads us onward in search of the priceless truths so coveted by adventuring human wisdom.

Amidst prismatic hues Science traces out the mysterious language of the spheres, and points us not unhopefully to those yet unsolved enigmas which seemingly transcend all reach of human intellect. Can she explore the dim "recess of wisdom and of wit," and tell us of the secret and material springs from whence immortal thought is born? Can she unravel the miracle of life, or penetrate the profound silence which unfolds the genesis of force and matter? Who that is enrolled in membership of our infant Institution shall win for himself eternal fame, by pointing the way through one of these unexplored and awful mysteries?

ADDRESS

At the Grand Celebration of the Opening of the St. Louis Bridge, July 4, 1874.

My Friends and Fellow-Citizens :

The love of praise is, I believe, common to all men, and whether it be a frailty or a virtue, I plead no exemption from its fascination. The wish to merit the good opinion of our fellow-citizens, and especially of those whom we respect and esteem, is a laudable stimulus to effort. It is the grand motor which actuates the mind of man to attempt the accomplishment of worthy deeds. Therefore, the words of eulogy which partial friends have to-day expressed so eloquently are, to me, on this occasion peculiarly grateful; not because I am so vain as to think that I, individually, merit one tithe of the praises they have uttered, but because I learn by it, and by the pageantry of this occasion, that the magnitude of the labors and the value of the work accomplished by the worthy men with whom it has been my good fortune to be associated during the last seven years, is to-day fully recognized by the people of St. Louis.

Yon graceful forms of stone and steel, which prompt this wonderful display, stand forth, not as the result of one man's talents, but as the crystallized thought of many, aye, very many minds, and as the enduring evidence of the toil of very many hands ; therefore I would forfeit my self-respect and be unworthy of these pleasing evidences of your good will, if on this or any other occasion, I should appropropriate to myself more than an humble share of the great compliment you are paying to those who created the bridge. It is of itself a high privilege to feel that I stand before you as the representative of a community of earnest men, whose combined labor, brains and wealth, have built up this monument of usefulness for their fellow-men. For them and in their names I thank you for this magnificent evidence of your approbation. It speaks to the heart of each one of them, and breathes an assurance that their efforts in the cause of human progress are justly appreciated.

I should like, my friends, to tell you something of the bridge. but so much has been written about it, and it has been so often described, that it seems almost unnecessary. Besides I am admonished by the occasion that I must be brief.

Everything which prudence, judgment and the present state of science could suggest to me and my assistants, has been carefully observed, in its design and construction. Every computation involving its safety has been made by different individuals thoroughly competent to make them, and they have been carefully revised time and again, and verified and re-examined, until the possibility of error nowhere exists. When its first deep pier reached the bed rock 110 feet below the surface, those who knew nothing about the care that was used in insuring success, expressed their gladness that my mind was relieved by the occasion. I felt no relief, however, for I *knew* that it must go there safely. When the first arch was closed, Mr. J. S. Morgan, of London, whose firm has supplied so many millions for this work, and whose confidence in it has contributed so much to its success, wrote me, hoping that the closing of the arch had made me as happy as it had him. I replied that the only happiness I felt was in the relief that it afforded my friends, for I *knew* it would be all right, and I then reminded him that two other arches yet remained to be erected, and that he might rest assured that such care had been taken to insure their safety that disaster to either of them was impossible. Yesterday friends expressed to me their pleasure at the thought that my mind was relieved after testing the bridge, but I felt no relief, because I had felt no anxiety on the subject. I could get no more engines or I should have imposed still greater loads upon it; for if I knew that thrice fourteen locomotives were to be put on each span and the densest crowd of humanity which was ever packed together stood upon the upper roadway above them, I should feel no anxiety whatever for the safety of the structure, for I know it is capable of bearing up vastly more than that, and I trust that those who use it hereafter will put the same implicit faith in its strength that I have. Its ability to sustain its burden depends upon laws which are as immutable as the Creator Himself, and when these laws are properly applied in estimating its strength, there need be no fear of the result.

I am justified in declaring that the bridge will exist just as long as it continues to be useful to the people who come after us, even if its years should number those of the pyramids. That its piers will thus endure, but few will doubt, while the peculiar construction of its superstructure is such that any piece in it can be easily taken out and examined, and replaced or renewed, without interrupting the traffic of the bridge. The effect of temperature upon the arches is such that in cold weather the lower central tubes, and the upper abutment tubes composing the spans, are so relieved of strain that any one of them may be uncoupled from the others and easily removed. In hot weather the upper ones of the centre, and the lower ones near the piers, may be similarly removed. In completing the western span two of the lower tubes of the inside ribs near the middle of the span

were injured during erection, and were actually uncoupled and taken out without any difficulty whatever, after the span was completed, and two new ones put in their place within a few hours.

This is a feature in its construction possessed by no other similar work in the world, and it justifies me in saying that this bridge will endure as long as it is useful to man. He, alone, will destroy it, for the earthquakes may rock its piers and shake its elastic arches in vain.

I should like, on this occasion, to mention the names of each one of those with whom I have been most intimately associated, and to whom you are mainly indebted for the erection of the bridge. One absent chord, however, will mar the harmony of the sweetest harp, no matter where be its place in the scale, nor how loving be the fingers which sweep the strings; and so would it be were I to trust my memory to-day in the attempt to name each one in that honored list. The history of the bridge will, however, one day be written, and there, on its brightest pages, will be found the names of our honored President, Gerard B. Allen, Dr. William Taussig, Col. J. H. Britton, J. R. Lionberger, Barton Bates, John Jackson, aad the other Directors of the company, to whose unswerving confidence and kindness I owe a ceaseless debt of gratitude. There, too, will be recorded the valued and indispensable services of Flad, Roberts, Pfeiffer, Dwelle, Cooper, Devon, Gayler, Schultz, Wieser, Smith, McComus, Wuerpel, Klemm, and a host of others, earnest, faithful and accomplished; while among those who are prominently identified with the construction of the bridge, and whose familiar faces and names are recognized all over our city, are James Andrews, who will stand conspicuously forth as the talented and indomitable master mason who built the stone work of the bridge, and all of the tunnel north of Market street; and Walter Katte and his tireless foreman, McMahon, will be recorded as the skilful engineer who swung its steel arches into place. The caissons beneath the piers will be identified with the name of their energetic and talented builder, Capt. William S. Nelson, while the east approach will be cited as one of the many creditable works of Col. Shaler Smith, and the southern portion of the tunnel constitute an evidence of the industry of Skrainka & Veitch.

Before closing I wish to refer to one subject connected with the history of the bridge, which, while it constitutes one of its most instructive pages, will be shaded with sorrow and regret. A great work is rarely erected without the sacrifice of human life, and our bridge is no exception to the rule. So far as it lay in the power of the chief engineer and his assistants, every caution was used to prevent a loss of life, and I refer with pleasure to the fact that not one man on the work has been killed by the breakage of machinery, tackle, staging, or anything of the kind under the control of the engineering corps of the bridge. Many were, however, killed by falling from scaffolding and in various other ways. The loss of life in the caisson

of the east pier resulted from the fact that no such depth had been attained before, and experience of others could not be had to guide our operations in it with safety. In the east abutment pier, which was sunk a few feet deeper, this mortality was prevented by the sad experience gained in the other. Let us not to-day forget these faithful toilers, no matter how humble they were, who contributed their lives in the erection of the structure, whose completion you signalize so notably.

Since the work was begun we have seen three of its most valued friends placed beneath the sod. John J. Roe, one of its largest stockholders, most valued directors and earnest advocates, was borne to the earth by a sorrowing host of our best citizens a few years ago. After him, Charles K. Dickson, the first President of the company, was stricken down in the midst of his usefulness. He was emphatically one of the fathers of the bridge, and it is scarcely saying too much to declare that its construction would have been indefinitely delayed had it not been for the zeal displayed by him at the inception of the enterprise. He was one of God's noblemen, possessed of every manly virtue, with enlarged views, clear and quick perceptions, and a generous heart. He was one of the very best of men. After this sad loss to the bridge company, death placed his hand on his successor, and our second President, Wm. M. McPherson, was laid in the tomb. Here again the bridge lost one of its most earnest friends, whose active mind, untiring energy and remarkable talents were devoted to its completion. These distinguished citizens each contributed largely to the success of the enterprise you are honoring. None now present ever felt for it a deeper interest than that which animated them. Each one was my warm friend, and Charles K. Dickson was emphatically so. The sadness which fills my heart at their absence on this day of triumph cannot be expressed in words. We can but exclaim:

"How had the brave, who fell, exulted now!"

BANQUET.

Response to Welcome Address of the Mayor of St. Louis at the Banquet Given at the Southern Hotel, March 23, 1875, in Honor of the Passage by Congress of the Jetty Act to Improve the Mouth of the Mississippi.

Mr. President and Gentlemen:

When I was told, on my return from Washington, that my friends intended to honor me with a dinner, I thought the cloth would be spread for a quiet little party of but ten or fifteen. I had then no expectation of being the favored recipient of this magnificent evidence of the hospitality of several hundred merchant princes and noted citizens of this great city. I did not then suppose that a score or two of eminent gentlemen from our own and sister States of this Union, whose lives are interwoven with their country's history, who are honored for their talents abroad and their virtues at home, would be called here to add to your banquet the pleasure of their presence, to grace it with their eloquence and wit, and gild with their bright names the memory of this occasion. To assure you that I am pleased, aye, delighted beyond utterance with these extraordinary tokens of your regard, would but feebly express the emotions of a heart overflowing with pleasure and gratitude. Believe me, sir, I jealously prize even the slightest evidence of esteem from those I respect. You may then imagine, but I cannot express, the feelings which crowd at this moment upon me, when so honored by those I regard and love, and who now surround me in such numbers that the very atmosphere seems fragrant with the breath of friendship. The greeting you have given me, and the partial words just uttered by one whose skilled speech and warm heart give to flattery every semblance of truth, make me over ready to accept much more than my proper share of the exquisite compliment you have prepared ostensibly in my honor.

I cannot, however, even in the ecstacy of the moment, be unmindful of the fact that this enthusiastic demonstration has a higher purpose than that of a graceful compliment to a private citizen, no matter how proud a place he may hold in your esteem.

The wires, sir, which will before the blush of morning flash to every town and city in the land an account of this notable incident, will

chronicle the fact that the enterprising citizens of St. Louis in honoring, far beyond his merits, one who is proud to be known as their co-laborer in the grand work of human advancement, have in this way given a signal evidence of the intense interest which they feel in that great principle of political economy called cheap transportation.

These two simple but talismanic words sound the key-note of prosperity throughout the valley of the Mississippi river. They also embody a principle so full of benefit to humanity that they constitute a theme worthy of the highest effort of the philanthropist, for they are synonymous with "cheap food" to mankind everywhere. They mean higher values to the producer and lower prices to the consumer.

Hence, cheap transportation may be likened to the heaven-born quality of mercy, which the poet tells us is "twice blessed," for, like mercy, "it blesseth him that gives and him that takes." Whenever a notable reduction in the cost of transportation is made in any part of the world, whether it be by improvements in railroads, steamships, elevators, or other important methods of transporting and handling the various products of industry, or by piercing mountain chains, spanning rivers, or uniting oceans, and thus overcoming the various obstacles to convenient or rapid transit, the benefits which flow from it are not confined to the locality in which it originates. Like judicious charity, they bless home first, but like circling waves which are engendered upon the waters when we cast out our bread upon its surface, they are impelled onward and outward in constantly expanding amplitude, until the most distant shore feels their influence.

These beneficent effects will come like a rich and unlooked for heritage upon the people of this vast and productive valley, when the obstructions which to-day virtually close up its only natural outlet to the world's commerce are forever removed from the mouth of the Mississippi river. When that inland sea which bathes your wharves shall bear the grand tributes of its mighty affluents unvexed to the Gulf of Mexico, there is not a farm house nor a hamlet within the precincts of this whole nation that will not feel the blessed effects of its disenthralment. When the millions of tons of breadstuffs, provisions, cotton, iron, and the multitude of other necessaries of life, that are produced in such abundance throughout the 1,200,000 square miles which constitutes our valley, shall be free to pass out from this garden of the world by its natural and cheapest outlet to the various marts of the earth, the benefits which will accrue to humanity wherever the white sails of commerce are bent to the breeze, will constitute a revolution more wide and beneficial than anything that history has recorded in the last hundred years.

It is because you, gentlemen, recognize these facts, and because you have labored earnestly to accomplish these grand results which the near future now holds in promise for you, that you are this night

drawn together around the social board to evince the deep interest you feel in securing an open river to the sea, through which the pent-up commerce of an empire, whose present gateways are controlled by railway magnates, may forever flow untaxed and untrammeled to the markets of the world.

Do not imagine, sir, that I am not fully impressed with the great responsibility I have assumed in undertaking to remove the formidable obstructions at the mouth of the Mississippi. If I had underestimated my obligations to you and to my countrymen in this matter before this evening, I should have needed nothing more than the present demonstration of your interest in my success to have been fully impressed with the magnitude of this responsibility.

If the profession of an engineer were not based upon exact science, I might tremble for the result in view of the immensity of the interests which are dependent upon my success. But every atom that moves onward in the river, from the moment it leaves its home amid crystal springs or mountain snows, throughout the 1,500 leagues of its devious pathway, until it is finally lost in the vast waters of the Gulf, is controlled by laws as fixed and certain as those which direct the majestic march of the heavenly spheres. Every phenomenon and apparent eccentricity of the river, its scouring and depositing action, its caving banks, the formation of the bars at its mouth, the effect of the waves and tides of the sea upon its currents and deposits, are controlled by laws as immutable as the Creator, and the engineer needs only to be assured that he does not ignore the existence of any of these laws, to feel positively certain of the result he aims at.

I therefore undertake the work with a faith based upon the ever-constant ordinances of God himself; and so certain as He will spare my life and faculties for two years more, I will give to the Mississippi river, through His grace, and by the application of His laws, a deep, open, safe, and permanent outlet to the sea. Thanks to the able discussions which the phenomena at the mouth of the Mississippi and the remedial treatment proposed for its improvement, have called forth from such distinguished engineers as Gen. Barnard, Sir Charles Hartley, Mr. Bayley, and other prominent civil engineers, and of those which composed the select commission specially charged to investigate the subject by Congress, and which discussions have been so much more thorough and exhaustive because of the ability and tenacity with which several eminent military engineers of our country maintained opposite views, there is now, I believe, no longer any doubt in the public mind with regard to the jetty system.

It is well known that I advocated the application of this system at the Southwest Pass, while the eminent commission of engineers referred to and the Congress of the United States have given their preference for the improvement of the South Pass, the chief reason

being one of economy. If it be found that the greater pass shall ultimately require the same treatment, it will prove to be a mistaken economy. For the gratification which it will afford my friends, I will here state that the selection of the South Pass will prove no misfortune to me in any case, and the work I hope to accomplish there will be an immense improvement upon the present condition of things.

Before closing my remarks, if the occasion permitted, I would like to give emphatic testimony to the value of the services of many of the gentlemen in both houses of Congress to whom I think the thanks of the country are due for securing the passage of the bill for improving the mouth of the river.

I cannot on this occasion hope, however, to name the many distinguished statesmen who deserve praise in this connection, nor even those to whom I feel personally indebted for confidence and courtesies. I will simply state that the entire delegation from this State have placed me under lasting obligations by their personal kindness, and that all of them were indefatigable in aiding to pass the measure.

Especial praise is due to your Senators and to the representatives of your city.

I should do violence to my feelings upon this occasion were I to close my remarks without alluding to the immense influence of the press of this city in winning this victory, and expressing my profound thanks to its proprietors and editors for the uniform kindness and consideration I have received through so many years and through so many controversies, from them. I believe no man living owes more to the press of your city and State than I do, for the defense they have so often made of myself against many misrepresentations and unjust attacks, during the past fifteen years of a very laborious life. In all that time I have had nothing but kindness from them and praises much beyond my merits; and as mean as it may seem in me to confess it, they have never had a dollar from me in return for it all. In the controversy respecting the jetty system my thanks to the press require a wider scope, as I received in it the support of no less than six hundred different journals, for all of which I feel deeply sensible. I can only add that while I know I have deserved much less, I shall strive by every effort to merit a continuance of the potent favors of the press for which I have reason to be so profoundly grateful, and I only ask that the friendship of those who now honor me so greatly will not be withdrawn until I shall cease to labor for my country's advancement.

The action of the Merchants' Exchange of St. Louis—the ever faithful champion of your best interests—is known to you all. How can I speak of it? Shall I gild refined gold, or paint the lily? The action of that body is historic. Its aid to me I need not state, either

to this assembly or to the great valley of which our city is the center. It is known to all. That the Exchange has my hearty acknowledgments in as true as, that this recognition is an inadequate return for unvaried confidence and kindness.

ADDRESS.

AT THE DEDICATION OF THE GRAND HALL OF THE MERCHANTS' EXCHANGE OF ST. LOUIS, DECEMBER 5, 1875.

Gentlemen of the Merchants' Exchange:

With the honest pride which worthily waits on the accomplishment of a noble purpose, you are here to dedicate to Commerce this splendid witness of your enlightened munificence: to consecrate to the service of your patron goddess, whose mission is emphatically one of "peace on earth and good will to men," this superb temple, in which for her uses your gifted architect* has, with most cunning skill, fashioned these spacious halls and convenient chambers with massive strength and dignity, and clothed the enduring fabric of his genius with all the graceful harmonies of art. Complete in its appointments, it will stand for ages in calm repose, an eloquent witness of your intelligence, and of the energy and public spirit of the distinguished fellow-citizen [*turning to Col. George Knapp*], who labored so earnestly to concentrate in this form the characteristic liberality of the commercial men of St. Louis.

Votaries of Commerce! Absorbed in the daily routine of your high profession, can you pause to contemplate the full significance of this notable occasion? You are about to inaugurate a new era in the wonderfully instructive history of the Mississippi Valley; and this stately monument of your enterprise will be revealed in silent grandeur to the coming generations as one of the great land marks in the career of commerce—who to-day with her electric nerves and breath of steam is recognized as the mightiest ruler man has ever known. Empires, Kingdoms and Republics alike confess her authority. She grasps the purse of state, and declares war or enforces

* Mr. Francis D. Lee.

peace, just as she lists; and though her realms embrace every land and ocean known to Christendom, with tireless energy she still unearths the occult wealth of continents, and sails her ships on untracked seas in search of further conquests. She rouses the inventive faculties of the mind; spurs art to its utmost endeavor; guarantees to labor its largest recompense; is the inspiration of science; the patron of learning; the apostle of civilization; the friend and pioneer of religion, and the uncompromising advocate of honor and fair dealing in every quarter of the globe. Annihilating time and space, her lavish hand brings to the cottage its comforts and to the mansion its luxuries; and on her enterprising and enlightened followers she bestows a wealth and influence that justly entitle them to be called merchant princes.

Oh! that I had even for this brief moment, a grasp of thought and an eloquence of speech worthy of the theme, that I might picture to the whole world in fitting words the great mission of Commerce in America, when she shall once be freed from the trammels that now embarrass her wealth-creating powers, and which limit the grand sphere of American merchants.

It hath been said that he who causes two blades of grass to grow where but one existed, is a public benefactor; but I tell you here that he who removes the barriers that exist between the producer and consumer, and who lessens the cost and embarrassments that attend the interchange of the productions of labor, is worthy of the highest honors of the State. These are the grand problems which Commerce keeps constantly before the enlightened merchant. Every step in their solution raises the value of the products of human industry, even before they leave the farm, the mine, the workshop, or the factory. This stimulates production, and increases traffic. Therefore, the destruction of every obstacle existing between the producer and consumer, whether it be a natural or artificial one, is fraught with triple blessings to mankind.

He who daily seeks the market place for trade and barter, and who never ponders over the cognate questions involved in bringing the producer and consumer into closer relationship, and in freeing traffic from the trammels which legislative demagoguery, selfishness or misdirected patriotism have thrown around it, is but a simple drudge in the train of commerce, and is unworthy of the high title of merchant.

The solution of these questions should be the constant study of the true and enlightened votaries of Commerce, her merchant statesmen, her merchant princes. Merchants like these elevate humanity. They leave the impress of their practical wisdom upon the destinies of the State, and the monuments of their genius and liberality stand like beacon lights in after times, to cheer mankind onward in the grand march of improvement. Such men enlarge the area of civil-

ization, refinement, and constitutional liberty; and the highest honors which man confers upon his fellow man are within their easy grasp.

History is replete with instances of the vast influence which the eminent and sagacious votaries of Commerce have acquired in different ages. The crowned heads of Europe bowed in respectful homage to Leo the Tenth, the son of the great merchant, Lorenzo de Medici, and the blood of that merchant family honored the veins of some of the proudest monarchs of the old world. Royalty supplies no grander record of opulence, influence and culture, than that which traces the history of the commercial family of the Medici, through the long period of four hundred years.

In our own times, even the dust of an American merchant was deemed so worthy of honor before removal to its native land, that its brief sojourn in the classic Abbey of Westminster—a burial place sacred above all others to genius, eminence and royalty—is recorded on a stone tablet in the center of its grand old nave. There, surrounded by sculptured marbles, which bear the brief record of England's most illustrious dead, the generous respect of a great nation for the eminent merchant is touchingly manifested in the deeply chiselled and simple words, which tell all the world, that upon that spot rested for a few brief hours the mortal remains of George Peabody.

Returning to the great problems which Commerce presents for solution to her intelligent followers: these are all contained in this one comprehensive question: How can the easiest interchange of the productions of human industry be accomplished?

No intelligent man will deny that in proportion as the interchange of products is facilitated, there will be: first, increased value given to them while they are still in the possession of the producer; second, that production will be stimulated, by which commerce will be benefited and reap larger aggregate profits; third, that while the producers will be better rewarded, and the sphere and profits of commerce enlarged, the increase of production and facilities of trade will inevitably reduce the price of these products to the consumer. It is, therefore, evident, as these three classes, namely, the producing, commercial, and consuming ones, embrace the entire population of the State—that every man, woman and child in the nation, unless favored above the rest by some special legislation or individual advantage, is directly interested in freeing trade from every trammel and impediment, whether natural or artificial.

As there is scarcely a civilized nation to-day on the face of the globe where trade is so much hampered by natural and artificial difficulties as it is in our own, this broad question :—How can we facilitate trade? —is one that should over-ride every political, social or religious question in the land—for this is one affecting the wages of the labor, and

the rewards of the industry of every man and woman in the Republic. It is a question of national wealth or national poverty; and the poverty side of the question is pressing so closely upon the people at this moment, and all over the land, that it must be promptly met.

To facilitate trade, two great agencies are absolutely requisite. One relates to the conveyance of the property to market, and the other to the equivalent to be received in exchange for it. These are known by the general terms, TRANSPORTATION and FINANCE, and they are so inseparable in all mercantile transactions, that the first may be not inaptly termed the bone and sinew, and the last the nerve and brain of Commerce. They are indeed the chief handmaidens of commercial wealth, and the simplicity of the principles governing the seemingly complicated functions of each, and the harmony with which their actions respond to the ever-varying impulses of Commerce, possess for the enlightened merchant who fully comprehends them, the charm of philosophy and the rhythm of poetry.

The key-note of our national prosperity is sounded in the simple words, "Cheap Transportation." They should be stamped upon the stripes of our national banner and thrown to the breeze from every farm-house, mill and factory throughout the commonwealth. School-boys should be taught that the superior facilities for cheap transportation secured to Phœnicia, Athens, Venice, Genoa, the Florentine Republic and Holland, the commerce of the world. Each retained it until its rival became a cheaper carrier; and it is a notable fact that art, refinement, literature, history and eloquence attained in each State their highest development during its commercial sway.

When we examine the relations of Finance to Commerce, it must appear evident to every disinterested thinker that its proper functions cannot be performed perfectly, except on the basis of a medium of exchange that is recognized in every quarter of the commercial world. Gold and silver constitute the only medium thus universally recognized. An early resumption of specie payment is therefore essential to the restoration of our commercial prosperity.

Paper money is the resort of nations when in desperate strait, and unless managed with extreme caution, inevitably results in disaster to commerce. It should be strictly limited in quantity, and its redemption so guranteed, that its conversion into specie without loss and at the will of the holder may be positively assured under all circumstances.

The great historian, Hume, pungently remarks: "What pity Lycurgus did not think of paper credit when he wanted to banish gold and silver from Sparta. It would have served his purpose better than the lumps of iron he used as money, and would also have prevented more effectually all commerce with strangers as being of

so much less real and intrinsic value." There is a volume of wisdom in this paragraph.

But there are other absolute requisites to the commercial prosperity of America scarcely less important than cheap transportation, and probably of more moment than a sound national currency. I refer to the legislative trammels which to-day embarrass almost every department of Commerce in America.

While it is not denied by any one that cheap transportation is absolutely essential to our national prosperity, and while the most enlightened nations of the earth, England, France, Holland, Belgium, and Germany, witness by their great prosperity the advantage which flows from removing the trammels that cupidity or folly once placed upon their trade, we are actually erecting in every part of the country expensive structures to hamper and delay the traffic of our own people with foreign lands, as though it were possible to impose difficulties in the way of receiving their commodities, and not have these difficulties react to check the exportation of our own.

Tariffs are imposed which prevent us from purchasing in the cheapest markets of the world, and we are assured that the way to grow rich is to pay the highest prices for everything we consume; while not a tithe of the increase in price that is paid by the people goes to support the government, but to enrich, instead, a few favored monopolies.

Let Commerce be free. Tax the wealth of the citizens by any just methods, but do not interfere with his right to exchange with absolute freedom the products of his own labor for those of his fellow men; for that is an inalienable right which God made so for a wise purpose. This right is the great, if not the only stimulus to surplus production; and surplus production constitutes the real wealth of the world. Tax the wealth, but leave free and unrepressed the stimulus which creates it.

The right to liberty of person in man is no more sacred than his right to freely exchange the products of his labor, because the two are identical in principle, and you cannot invade the one without trespassing upon the other.

Then let Commerce be free. Let it not be said that a great nation claiming to be the home of liberty, and which has at such terrible cost of blood and treasure, stricken off the shackles from the slave, hesitates now to disentrall the labor of freemen.

Let Commerce be free as the genial sunlight whose blessed rays warm alike the prince and the pauper, and which gild with their glory the palace and the cabin, and she will fill the mansion of the great with refinement and luxury, and the cot of the laborer with comfort and plenty.

While cheap transportation is vitally essential to commercial prosperity, we are expending more money annually in the erection of cus-

tom-houses, to place artificial barriers in the way of commerce, than would be necessary to free the great rivers of this grand valley from their shoals and dangers forever.

Fifteen millions of dollars, judiciously expended, would give at least twelve feet of water all the year round from St. Louis to New Orleans. This would enrich America, and by opening to the commerce of the world the immense granary embraced in the giant arms of the Mississippi, would cheapen food, and bless mankind, not only at home, but on distant shores, as "far as the breeze can bear the billows' foam."

Instead of expending this $15,000,000 for this noble purpose, we see ten of it expended on a single granite pile in New York, and the remaining five will in all probability be exhausted in completing the custom-house in your own midst. The uses for which these costly edifices are designed, are a reproach to the intelligence of the age. While the great want of the country is cheap transportation, our laws forbid our American ship-owner from purchasing his ships wherever he can buy the cheapest, and thus interferes with his supplying to his countrymen this great essential of our prosperity, and leaves the carrying trade of America hopelessly in the hands of foreigners. One of England's most illustrious statesmen justly declared: "Whosoever commands the sea commands the trade of the world. Whosoever commands the trade of the world commands the riches of the world, and consequently the world itself." With the splendid advantages which nature and American genius give us to compete for the commerce of the world, we have the humiliation of knowing that to-day three-quarters of our own commerce upon the ocean is carried for us by foreigners.

How long must such lessons as these be thrust upon us before we can be taught wisdom; before we can abolish forever this mis-called policy of protection? How long must it be before we can throw open these prison-houses of trade, and let Commerce be free? They are the promoters of sectional and social ill-will; the barriers to international amity: and the harbors of commercial leeches, where the smuggler and the perjurer hold the honest merchant at disadvantage.

Demand from your law-makers the abolition of custom-houses, and the creation of a plain and just system of providing the requisite revenues of the State, that shall leave commerce free. Do not be cajoled by the public patronage, which expends a few hundred thousand per annum in their erection, and which, by their blighting influence, deprives you of countless millions; but demand that this worse than waste of money be appropriated to deepen your great rivers, and construct the canals necessary to join their tributaries with the ocean, and encourage the construction of your great transcontinental railways.

Let your ship-masters buy their ships where they find them cheapest, and float the stars and stripes above everything that belongs to

your countrymen. Let Commerce be free, and honest competition will soon solve the great problem of cheap transportation on land and sea.

Let Commerce be free, and manufactures will then feel a healthful development, uninfluenced by the fear of altered tariffs. Her workshops, mills and factories will then, more than ever, constitute the nursery from whence liberty, in every land and age, has called forth her sternest advocates of equal rights and genuine democracy.

Let Commerce be free, and the disenthrallment of labor will be complete. Then will honest toil be truly dignified and honorable, and then will agriculture, once deified in ages past, again be recognized as the guardian goddess of manly independence, and the shelter of every household virtue.

BRIDGES.

THE ST. LOUIS BRIDGE.

LETTER TO THE EDITOR OF ENGINEERING, LONDON, ENGLAND, PUBLISHED DECEMBER 11, 1868.

SIR—My attention has been recently called to your remarks on the Mississippi bridge at St. Louis, on page 285 of your present volume, and I beg that you will allow me to supply, if possible, such explanations as seem to be wanting in my report upon that structure, lately republished in your journal.

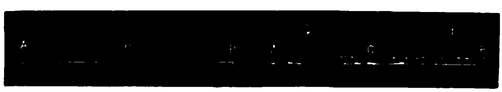
You say: "In fact, the essential part of the bridge is a curved rectangular beam, 8 ft. by 44 ft., the former dimension being the vertical depth of the bracing, and the other one the distance apart of the face ribs, which are firmly tied together by horizontal bracing. There can be no question as to the lateral stability of the structure, but the depth of vertical bracing is so small in comparison to the span—8 ft. to 515 ft.—that it is absolutely necessary to consider the question of stability in that direction. Now, there must obviously be some limit below which the depth of the arched rib could not be reduced, even if the load were always uniformly distributed, and the mathematical position of the center of pressure corresponded with the centre line of the rib. Thus, if the rib were but 6 inches deep, it could no more maintain its form for an instant than it would if built of ropes. Why a depth of 8 ft. should be assumed, as it is in the calculations, to afford perfect immunity from all disturbing forces, we are at a loss to guess."

In the explanation I propose making of the chief features of the ribbed arch by which this small depth becomes safe and practicable, it is important to keep in view the fact that cast steel, of which the arches will be made, has been satisfactorily proven to be capable of resisting fully seven times more stress in compression than cast iron, within the elastic limits of the two materials.

In the equilibrated arch, either upright or suspended, the bracing is under no strain from the weight of the load or structure. When moments of flexure occur from the disturbance of equilibrium, as in

partial or moving loads, or excess of weight in some portion of the structure itself, shearing strains are produced which are resisted by the bracing. The upright arch is usually braced in the spandrils. To the suspension arch the bracing is generally applied in the form of a girder supported by the cables or arches, as in the Niagara suspension bridge. The upright arch may also be retained in form as effectually as the suspended one, by a girder placed over, or below it, and securely united to it by vertical struts or suspenders. The suspended arch, under the effect of an unequal distribution of weight, *if flexible*, assumes a change of form by which the various parts of the arch are so disposed in new curves that their gravitation serves to re-establish the equilibrium of the whole. The lighter the moving load is in proportion to the weight of the arch, the less will it alter its form. When the wave created by the moving load in a roadway supported by a flexible suspended arch is not objectionable (as in long span bridges designed for ordinary travel only), a smaller proportion of girder power, or bracing, than would be required for the upright arch of the same span, weight and form, will give equal resistance to deflection. This is because a change of form to the upright arch, caused by an unequal distribution of weight, does not tend to re-adjust the disturbance of equilibrium, as it does in the suspended form, but to increase it. As the necessity of less bracing in the latter results solely from a change in its shape, it follows that if it be so thoroughly braced as to prevent this alteration of form, the bracing alone must resist the disturbance of equilibrium, just as it does in the upright arch. Consequently, if the wave in the roadway, which is a result of the changing form of the arch, be objectionable, as it is in railway traffic, the suspended arch, if adopted, should be so perfectly braced as to prevent its change of form, as far as possible; and as a given load can only exert a certain force upon the same arch, whether the latter be upright or suspended, it is evident that to secure a very thorough resistance to deflection, will require as much strength of girder or bracing in the one form of arch as in the other.

The great difference in strength required in a girder that is self-supporting, and in one that is supported by an arch to resist deflection in spans of equal length, is clearly set forth in the following extracts from the very interesting pamphlet of Mr. Peter H. Barlow, C. E., entitled "Observations on the Niagara Suspension Bridge," (page 27):



"If the beam, A B, Fig. 5, be divided into two beams by being supported at C, the two half beams, A C and B C, will deflect one-eighth

of the amount of the entire beam, A B, with the same weight. Let us assume this to be a girder attached to a chain, and a load placed at D, the effect will be to distort it into the shape shown in Fig. 6.

"The deflection by the weight at D will cause a corresponding elevation at the point, E, and the girder will assume the shape represented by dotted lines in the figure, to produce which a force equal to double that for a given deflection on half the beam is required, from which it is evident that the wave produced by a given weight at D will only amount to one-sixteenth of the deflection the same weight will produce on the entire beam resting on its two ends.

"In the above proposition it is assumed that the beam is supported at its centre point only; in practice, when attached to a suspension cable, it is supported at various points of its length; the difference between the wave of a supported girder, and the deflection of an unsupported girder, will therefore be greater than one-sixteenth. In order to arrive at the result by experiment, I had a model of the proposed Londonderry bridge, on a scale of one-thirty-third of the actual span, the length being 13 feet 6 inches between the bearings, a length exceeding that of the average of the models used by the Iron Commissioners in their experiments, and is amply sufficient, due allowance being made for the scale, to determine the accuracy of the deflections on the actual girder.

"These experiments gave a mean result of one twenty-fifth; so that, it being first determined what amount of deflection is to be the limit with a given load in a given bridge, you have only to arrive by calculation at the sections of metal of a girder of the same depth which would deflect twenty-five times that amount."

"To illustrate the mode of proceeding in the intended Londonderry Bridge: It was decided by Sir W. Cubitt that the depth of girder should be 16 feet 6 inches, and that no wave or deflection should exceed 1.32 in., with 100 tons. I obtained by deduction from the deflection of the Boyne Viaduct, Newark Dyke Bridge, Britannia Tube, etc., that a girder of 3,700 tons, of the depth of 16 feet 6 inches, would be deflected 1.32 in. with a weight of 100 tons. One twenty-fifth, or 150 tons, is, therefore, the weight of girder required for the Londonderry Bridge."

In addition to the support given to the girder by the arch at its center, there is another reason why so small a proportion of strength is required in it when compared with the self-supporting girder of the same span. In the latter a very large portion of the weight of the structure and of the maximum load is borne by the bracing; whilst with the arch the girder bracing bears no part of this weight. It has simply to resist the shearing strains of the partial or unequally distributed load, and the strains created by extremes of temperature.

By trussing an arch with a horizontal girder of iron or steel, the

alterations of length produced by atmospheric changes in the girder must be provided for The increased resistance to deflection imparted to a beam by fixing its ends into the walls supporting it, is well known. Had Mr. Barlow's experiments included this feature in the girder of his model, the results would have been still more favorable. When we desire to avail ourselves of this advantage, however, the expansions and contractions of a straight girder involve very serious difficulties. These are avoided, and this advantage made available in the Mississippi Bridge by curving the girder upward, and incorporating it into the arch itself; thus forming, by the union of the two, the *ribbed arch*. By this means we also dispense with the connections required between the arch and straight girder, and thus economize material, and at the same time, simplify construction.

The alterations in the length of the arch, caused by heat and cold, elevate and depress it at the center. If trussed with a straight girder, the latter would also be raised and lowered in the center by the action of the arch. If the girder were bent upward, tension would be created in its upper member, and compression in the lower one, and these strains would be reversed by extreme cold, as the girder would then be bent downward. It is evident that these strains would be increased by increasing the depth of the girder. By lessening its depths they would be decreased, but then we should require greater sectional area to enable the girder to resist the shearing strains of the moving load. By curving the girder and incorporating it into the arch, the same effects of temperature and unequal loading still exist, consequently, a medium in the depth of the bracing must be found where these conflicting conditions can be most economically harmonized. Several careful computations for greater and lesser depths proved that the most economic one for their mutual adjustment in the ribs of this bridge, consistent with the desired resistance to deflection, was eight feet. By this depth, where the greatest extreme of temperature occurs, and at the same time the most intense shearing strains are produced by the maximum load progressively covering the bridge from one side (the other side being unloaded), the greatest compressive strain in any part of the rib will not exceed 25,000 pounds per square inch of section. Tension will in no place be created except near the abutments, where the sectional areas are increased 50 per centum. The carriage-way and footpaths must be densely filled with people, and both railways covered with locomotives to make up the maximum load estimated for 3.2 tons per linear foot. Such a load could only be placed on it purposely, and in the ordinary business of the bridge it would scarcely ever have more than one-third of this weight to sustain.

Spandril bracing would involve the necessity of a straight metallic girder or member over the arch, which would be constantly changing its length with heat or cold. In the climate of St. Louis these

changes in length would equal six or seven inches. The alterations in the height of the arch, from the same cause, and the expansions and contractions in the spandril filling, would subject any adjustment of these various parts to alterations so extreme as to make that system objectionable in arches of unusual dimensions if exposed to such great atmospheric changes.

You express the opinion "that an arched rib, *per se*, is neither more nor less than a long column, and that it should consequently be treated as such." The remarks which follow this opinion indicate that you believe similar forces would produce identical results in both, as you say, "Now, how it is that in calculations concerning arched ribs, or, in other words, curved columns, the unit strain should be assumed uniform if the mathematical position of the center of pressure at any point corresponds with that of the center of gravity of the cross section at the same point, whilst in a straight column, under similar conditions, it is shown by experiment to differ so widely from it, is not to us apparent."

I think there are features of so much dissimilarity in the vertical column and arched rib, that the effect of vertical pressure upon the one furnishes very little data from which to deduce the strength of the other. If one of the ribs in question were straight and vertical and the maximum pressure were applied to it in the direction of its length, the least difference whatever in the resistance of its two parallel members would result in a curvature of the column. A very slight difference in their strength would produce a flexure in so long a column equal to half its diameter. This would bring the center of pressure through the axis of the weaker member at the middle of the column, which would relieve the stronger one of all pressure in that section, and throw the entire load on the shorter or weaker member. A greater flexure would create positive tension in the stronger member, and this would increase the compression in the other; so that instead of simply sustaining 25,000 pounds per square inch, the weaker member wound have to bear more than twice that pressure. Thus the stability of a long slender column might be endangered by a slight difference in the modulus of elasticity of the material in its two parallel members. This could not occur in a parabolic rib. In it a similar compression throughout the rib could only be the result of an equally distributed load, and, so long as this remained, it would not matter whether nine-tenths of the total sectional area existed in one member or the other of the rib; or if the elastic resistance of the two were quite different. Such a difference would not result in compelling the weaker to sustain the greater burden, as in the straight column, but would subject the stronger member to an increased pressure proportioned to the weakness of the other, whilst the line of pressure would bear the same relative position to the

longitudinal axes of the rib that it would do if the sum of the resistance of the two members were equally divided between them.

When transverse forces act upon the arch and upon the straight column, longitudinal compression is produced throughout the entire area of any section of the arch by such forces, but it is impossible to create compression by such forces in but one-half of the sectional area of the column. Any equally distributed force acting transversely to the axis of the column will create tension in one-half of any given section of it, whilst a force equally distributed and acting transversely to the line of arch will not create tension in any part of any section of the arch.

"In the Mississippi Bridge," you say, "the least dimension of the column is about one sixty-fourth of the length; but on account of the curvature of that member, it is in effect, to a certain extent, supported at the center of its length; hence, the equivalent ratio will be greater than the preceding fraction. We have not investigated the question minutely, but theory appears to indicate that the equivalent ratio would be $\frac{1}{64}\times\sqrt{2}=\frac{1}{45}$th of the length. If this be so, the elastic resistance of the steel to be employed in the bridge should have been deduced from a bar 45 inches long by 1 inch diameter, instead of from that of a bar 12 inches long only, as appears to have been done."

Mr. Barlow's experiments prove that the equivalent ratio of one-forty-fifth (which is assumed by you, as you admit, without careful investigation), is not correct when applied to a horizontal girder supported by an arch. A few simple experiments, easily made with a small vertical column of similar proportions, will prove it incorrect when applied in that manner. If it were correct, however, I do not clearly see why, in experiments made to determine the resistance of the steel under compression, we should take the proportions of the rib for the bar under trial, instead of those of the members of which the rib is composed. In any ordinary form of truss bridges, the proportions of the struts, or of the top members between the points at which they would be braced, would be taken in such experiments, and not those of the truss itself. The ribs will be formed of columns twelve diameters in length, and for this reason the preliminary experiments referred to were made on columns 12 inches long and 1 inch diameter, to determine the elastic limit of the steel, and also to ascertain what force beyond the elastic limit was requisite to produce flexure in a steel column of those proportions.

Previous to this expression of views by you, it had not occurred to me to consider the ribs of this bridge as so many long columns. If examined in that light, however, I believe they will not be found wanting in strength.

A vertical column 64 times its least diameter in length, stayed at

the middle, with its two ends firmly socketed or fixed, and composed of cast steel having a maximum elastic resistance to compression of 50,000 lbs. per square inch of section would be quite competent to sustain safely one-half of that weight, even if one-twelfth of the length of the column at each end of it were not enlarged 50 per centum in sectional area. The maximum load and the weight of the span together, however, only exert a pressure of about 16,000 lbs. per square inch of section in the ribs of the bridge. When the same column is curved and longitudinal compression is produced in it by forces acting transversely to its axis, it will exhibit a much greater degree of resistance.

A straight iron column 50 inches long, 1 inch wide, and one-fourth of an inch thick (or 200 times its least diameter in length), would scarcely be able to support 200 lbs. upon it if vertical, but when bent in the form of a circle and subjected to an equally distributed exterior pressure, it will sustain a crushing force in the direction of the circle nearly twenty times as great. Explosions of several cylindrical boilers 42 inches diameter, made of one-quarter inch iron, and containing 16 inch flues of the same thickness, have occurred, without injury to the flues, on the Mississippi river. To burst such boilers would require a pressure of about 500 lbs. per square inch, allowing 30 per cent. for loss of strength in riveting. This superficial pressure on the flues would produce a compressive force on the iron in them equal to 16,000 lbs. per square inch of section. It may be claimed that this great strength was imparted to them by reason of the support given by the boiler heads in preserving their circular form, but Dr. Fairbairn's experiments establish the fact that the strength of a boiler flue is inversely as its length, and as those referred to were over 20 feet long, the support in the middle of the flues imparted by the heads must have been inconsiderable. If we admitted that it equaled 50 per centum the result would still show a far greater ability in the material when in the arched form to resist compression, than when used in that of a long straight column.

Very respectfully,

JAS. B. EADS.

Nice, France, November 15, 1868.

PNEUMATIC FOUNDATIONS.

LETTER TO THE EDITOR ENGINEERING, LONDON, ENGLAND, PUBLISHED MAY 16, 1873.

SIR:—I beg the favor of using your columns to correct some statements made by Colonel W. A. Roebling, C. E., in a recent pamphlet entitled "Pneumatic Tower Foundations of the East River Suspension Bridge."

I will briefly explain the caissons and air-locks designed and used by me in sinking the foundations of the St. Louis Bridge, to enable those who never saw them, nor the published plans of them, to understand more clearly the correction I wish to make.

The caissons or air-chambers used may be likened to a huge inverted pan. They were really enormous diving bells, on the tops of which the masonry of the piers was laid. A circular shaft, ten feet in diameter, containing a spiral stairway, occupied the center of each caisson, and was secured air-tight to the roof of it. This shaft was open at the top, and was built up with the masonry as the pier descended, the upper end of it being always kept above water. The lower end of the shaft was closed by a strong iron floor, to resist the pressure of the air confined in the air-chamber. This iron floor was only about three feet or four feet above the lowest part of the air-chamber. The chamber was nine feet high, consequently the shaft passed down through its roof, so that when the caisson finally reached the bed-rock, at a depth of about 130 feet below high-water mark, a person could descend the stairway, and stand on the floor of the shaft within three feet of the rock, in atmosphere of the natural density. At the foot of the stairway, in the side of the shaft, was an iron door opening into the air-lock, which was located adjacent to the shaft, and *within* the chamber. On entering the lock, which was six feet or eight feet in diameter, this door was closed, and the compressed air of the chamber was allowed to fill the lock. When this was done the inner door of the lock could be swung open into the air-chamber, and the visitor could then step out of the lock on to the sand within and beneath the air-chamber.

The part of the shaft within the chamber was formed of iron, and the upper part of white pine staves, varying in thickness from ten inches at the lower end of the shaft to three inches at the top. The staves were hooped together, and formed hollow cylinders eight feet long. These being placed one above the other, and rabbeted together as the pier descended, were enclosed in brick-work, against which the heavy masonry of the pier was laid.

The water penetrating the masonry compressed these staves, and kept them tight without any caulking whatever, and avoided the necessity of making the shaft of iron, which would have been more costly, and also enabled me to dispense with the still more expensive use of a water-tight envelope to enclose the entire pier,—something which I believe had never been done before, but which was afterwards done by Colonel Roebling in sinking the Brooklyn pier. I attempted to make the shaft of the east pier water-tight by building the part above the air-chamber in the form of a circular wall of hard brick eighteen inches thick, carefully laid in cement, but at the depth of sixty feet the water came through it and the masonry of the pier so freely that I was compelled to retain the exterior envelope on that pier. In the west pier I avoided this difficulty by using the wooden lining, and dispensed with enveloping that pier. This improvement was explained to Colonel Roebling during his examination of the work in March, 1870, before the sinking of his first pier.

Placing the lock at the bottom of the shaft, and within the air-chamber, made ingress and egress far more convenient than by any previous method, and rendered it unnecessary to make the shaft air-tight. It also enabled those who were employed to convey orders and instructions, or to supply tools or materials to the men working in the compressed air of the chamber, to be at the bottom of the pier, and close to them without being themselves within it. As the pier descended, it became necessary to lessen very much the duration of time to which the workmen were exposed to the effects of the compressed air. When a pressure of fifty pounds per square inch was attained, they were only permitted to remain in it forty-five minutes in the forenoon, and forty five minutes in the afternoon. This constituted a day's work for each man. It was important, therefore, that none of this time should be expended in climbing or descending ladders within this dense atmosphere. A step above the ground brought them to the air-lock, within which they remained only long enough to allow the abnormal pressure to be left off so as to permit the outer door to be opened, after which they emerged into the natural atmosphere at the bottom of the shaft. In the deepest pier a lift or elevator was arranged to work in the center of the shaft, so that the workmen after coming out were raised without further exertion or difficulty to the surface.

Colonel Roebling says in his pamphlet, page 71: "The idea of placing the air-lock at the bottom of the air-shaft, below the water level, in place of above it, in masonry caissons, is not new, having been proposed in England as long ago as 1831 by Lord Cochrane, and again by William Bush in 1841, and still later in 1850 by G. Pfaunmuller, of Mayence. It nevertheless remained for Captain Eads, in his St. Louis caissons, to make the first practical application of the same on a really large scale in this country." The only inference to be

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drawn from this statement is that I simply did what was suggested by some one else forty years ago.

Those who feel an interest in this subject will find Lord Cochrane's invention described in the English patent, No. 6018. In it, the lord admiral describes an ingenious application of the plenum pneumatic process to "subterranean excavations, sinkings, or mines." It commences by sinking a hollow cast-iron cylinder in sections, to form an air-tight shaft. On the top of these sections he places the air-lock. *After* the shaft is sunk, a second lock is placed at the horizontal drift, or tunnel entrance, at the bottom of the shaft, and one or more locks are suggested beyond this latter one in the tunnel; "in order," as he says, "to fill the space beyond the partition (or air-lock) with air in a greater degree of condensation than the condensed air wherewith the vertical shaft is filled. By this means the workmen who remain in the vertical shaft will not be required to work in air which is so strongly compressed as the air in which the workmen who are making the excavation at the end of the tunnel must work." Nowhere in his patent does he suggest any means of dispensing with the upper air-lock.

I am surprised that Colonel Roebling should have overlooked the fact that, by this plan it would be impossible to sink the vertical shaft to any considerable depth below the water line, if the shaft were not filled with condensed air. The plan, therefore, requires the air-lock to be taken off, and replaced each time a new section of the cylinder is to be added, as the sinking progresses.

Lord Cochrane did not propose to sink his shaft without a lock on top of it, and by the method he describes he could not do so. Mine, however, were sunk without any locks on the tops of them. By his plan the shaft could not be sunk with the upper lock detached, and the lower one attached; but mine were sunk precisely in this manner. The attempt to sink his shaft with this lower air-lock attached to its side, and the upper one omitted, unless some other distinctive feature were first combined with Lord Cochrane's device, would be as great an absurdity as one could commit. The Earl of Dundonald suggests no such absurdity, but says this lower lock is to be attached *after* the shaft is down. Imagine for a moment Colonel Roebling attaching his air-locks to his shaft *after* they were down to their destination, when the work was all, or nearly all done. When Lord Cochrane's shaft was down the chief work (drifting or tunnelling) was yet to be commenced, and this made a lock in the tunnel entrance necessary.

Colonel Roebling says, "The idea of placing the air-lock at the bottom of the air shaft, below the water level, in place of above it, in masonry caissons, is not new, having been proposed in England as long ago as 1831 by Lord Cochrane."

This is evidently an error. In no part of his patent did Lord Coch-

rane allude to "masonry caissons," or to caissons of any kind whatever, or to anything like a caisson. He did *not* propose "placing the air-lock at the bottom of the air-shaft below the water level in place of above it." On the contrary, he proposed to place it *above* the water level, and to keep it there, to retain the compressed air in the shaft.

The English patent of William Bush, referred to by Colonel Roebling, is numbered 9094. The statement respecting it is not open to the objection made against the reference to Lord Cochrane's, for Mr. Bush's description of his invention conforms to Colonel Roebling's text. He does describe an air-lock at the bottom of an air-shaft below the water level in connection with a caisson. I do, however, object to reference being made to me in this paragraph in a manner that leads the reader to infer that the location and arrangement of the air-shafts and locks in the New York caisson was due to the suggestion furnished Colonel Roebling by Messrs. Cochrane, Bush, and Pfaunmuller, instead of being copied directly from caissons of my own design, which were shown and explained to him and his consulting engineer, Mr. Horatio Allen, by me in the Mississippi river, under the piers of the bridge at St. Louis, a year or two before they were put in practical use by him at New York. The identity of the plans can be readily seen by any one who will take the trouble of turning to ENGINEERING for 28th of February, 1873, and folios 68, and 69, and 80 for January, 1871.

In the patent of Mr. Bush, the air-lock is not placed in the air-chamber or lowest compartment of the caisson, like mine, but in one above it, and this chamber is separated from the lower or working one by a flap or horizontal door. The excavated material is thrown up from below through this door, and when the upper chamber is filled, the workmen come out, and close the door of the lower chamber. The opening of the second flap door above, then enables the material to be hoisted out. The air-shaft does not extend down into the lower or working chamber, nor even into the one above it. Nor is the air-lock placed in this chamber; hence the process of hoisting out the material and that of excavating cannot go on at the same time. I do not think other engineers, after examining Mr. Bush's patent, will be likely to find any of his ideas used in the New York caissons.

Colonel Roebling's generosity to me in one point has made him unjust to himself, and has probably delayed his acknowledgments to Herr Pfaunmuller. The credit he gives me for making the first practical application of Pfaunmuller's ideas "on a really large scale in this country" belongs exclusively to himself. The sections of the Brooklyn caisson published by Colonel Roebling will give the reader an accurate idea of the designs for the piers of the bridge at Mayence,

proposed in 1850 by Pfaunmuller.* They were not used, however, for that bridge, and I do not know of their having been put in use until their adoption by Colonel Roebling in the Brooklyn caisson. Pfaunmuller's plan shows the air-locks placed on the top of the caisson, with a flap-door in the top and one in the bottom of the air-lock. The bottom of the air-lock is seventeen feet above the bottom of the air-chamber, hence the ground within the chamber would have to be reached by a ladder from the lock. The arrangement of locks and supply-shafts for introducing concrete into the air-chamber, as shown on the sectional drawings of the Brooklyn caisson, are in exact accordance with the plans proposed by Pfaunmuller in 1850.

The reader will only have to examine the published sectional drawings of Colonel Roebling's two caissons, to see the plans that were copied from Pfaunmuller's designs, and those which were copied from mine. He will then be able to judge how far Colonel Roebling is justified, after appropriating my plans without acknowledgment, in leading the public to infer that they were simply what had been proposed by Pfaunmuller nineteen years before I thought of them. By antedating Pfaunmuller's improvements, also, by those of Bush and Cochrane, he avoids all obligation to the former, while copying his plans into the Brooklyn caisson. The reader will, I think, perceive, however, a very marked improvement in the designs of the German over his two English predecessors.

I trust I shall not be understood as finding fault with Colonel Roebling for copying my plans in his New York caisson. On the contrary, I hold it to be the duty of an engineer to use the surest and most economic methods which are known in accomplishing his work, and, if possible, to improve upon those methods. Nor is the lack of inventive talent, whereby it is frequently possible to improve on the plans of others, or to devise new ones, at all necessary to constitute an able engineer, or to insure professional success. It is of much greater importance that the engineer, on whom rests the responsibility of a work, should be competent to select the best devices proposed by his assistants, or used by others, than to be able to invent novel ones himself. The obligation to adopt the best is, however, not incompatible with a generous regard for the rights or merits of others, and his professional reputation will never suffer by giving such credit to them as may be justly due.

Colonel Roebling's failure for the past three years to credit me with the plans appropriated by him was not deemed of sufficient moment to cause me to trouble the public with the matter, but, having frequent occasion myself for them when designing foundations of other

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* These can be found on page 32 of Erbkam's Journal for 1860 (published in Berlin), and also in a pamphlet published in 1850 by Pfaunmuller in Mayence.

works, his omission being now coupled with an effort to deprive me of all merit of originality in them, compels me, most reluctantly, to correct his statements, and show my right to use my own property.

Respectfully yours,

JAMES B. EADS.

St. Louis, April 16, 1873.

PNEUMATIC FOUNDATIONS.

LETTER TO THE EDITOR OF ENGINEERING, PUBLISHED SEPTEMBER 5, 1873.

SIR—I am again compelled to ask the favor of space in your columns to notice the recent letter of Colonel Roebling, published in your journal of the 27th of June.

To justify offensive personalities he states that I charged him with wholesale robbery, not only of my own ideas, but also those of several others.

My letter does not bear any such construction. I alluded only to my air-lock arrangement, not because he had not copied others, but because that was the only one with which he connected my name in his pamphlet. Nor did I charge him with the robbery of the ideas of *several* others. He stated that I had put in practical use the plan of Pfaunmuller. This I denied, and referred to his Brooklyn caisson to prove that it was he, and not I, who had adopted Pfaunmuller's design.

Colonel Roebling indirectly asserts that in my east abutment I copied the design of his Brooklyn caisson. This cannot be seriously believed, even by himself. His misapprehension of the principles involved in the construction of this caisson, as shown in his effort to prove their similarity, would be, to engineers familiar with both, a sufficient refutation of his assertion. He says: "There was the same compact, heavy timber roof composed of sticks crossing each other at right angles." It is a remarkable fact that no two sticks in the whole roof cross each other at any such angles. Aside from the fact

that both caissons were chiefly formed of timber, and that both contained air chambers, there was no similarity between them either in plan or construction. Besides, my caisson was nearly completed before I saw the Brooklyn caisson. From my inspection of that, and the experience related by Colonel Roebling in his pamphlet respecting it, I think it will never be copied.

He supports this assertion by another equally unfounded, viz: that I ridiculed the idea of using timber when he was in St. Louis in April, 1870; the inference being that I adopted it in this caisson in consequence of his visit at that time. To refute this, it is only necessary to state that the designs of the east abutment caisson were then completed. The contract for building it was made April 7, 1870. Besides, on page 26 of my report of May, 1868, I stated that it was intended to found this abutment on a *timber platform resting on piles;* it being at that time deemed by me too expensive to attempt sinking it to the rock, 136 feet below high water mark, as was afterwards done. I never approved of placing timber under the *channel piers*, for I believed the alternating pressures of the arches on each side of them, when loaded and unloaded, would produce an objectionable degree of oscillation in the piers if based on a material so elastic as timber.

Colonel Roebling asserts that the sides of the caissons of my channel piers were "notoriously weak." I have no knowledge of any weakness in them that was not easily remedied without creating any anxiety on the part of myself or assistants. Certainly none occurred of such importance as to become notorious.

I confidently predicted, he says, the upsetting of his Brooklyn caisson the first time it was inflated.

In this Colonel Roebling is mistaken. To lessen the draught of his caisson while towing it into position, Colonel Roebling proposed to *fully* inflate it. He claimed that it could be kept so while being towed. This I doubted. As it had no air-tight divisions in it, I believed it could not be kept from tipping or rolling when inflated, and that it would thus lose a portion of the air. On this simple difference of opinion he has the temerity to say that I predicted the *upsetting* of a floating wooden structure 102 feet wide and only 14½ feet deep, simply by the inflation of the air chamber within it.

With much satisfaction Colonel Roebling states that the cofferdam around his last pier proved a complete success, while for the lack of such foresight as he manifested, the one around my first one proved a failure. It would have been more generous, and quite as truthful, had he stated in this connection that mine answered all purposes until the pier reached the bed rock, and then it served to protect him while inspecting my caisson at that great depth. He could have added, also, that my improvements in the second pier, and in the east abutment, enabled me to dispense with the use of cofferdams entirely,

as soon as the caisson rested on the sand; and that I demonstrated this fact in time for him to have saved the useless expense of the cofferdam of which he boasts.

On page 75 of his pamphlet we learn that the bottom was dredged to a uniform depth of thirty-seven feet below high water to receive the New York caisson. The depth of the caisson was twenty-two feet of pine timber roof, and nine feet of air chamber, or thirty-one feet in all. At page 23 he shows that the caisson could be fully inflated without tipping. To submerge such buoyant timber with the caisson inflated would require at least eight or ten feet in depth of stone on top of it, as the area of the caisson was much greater than that of the masonry. This in high tide would leave the masonry from two to four feet above the water with the caisson landed on the bottom, and this proves how absurd is the statement in his letter that "the function of that cofferdam was strictly confined to the flotation of a caisson in deep water and a tideway, where any support by screws was out of the question." *Support* by screws in such a case, or by cofferdam, was totally unnecessary, the river bottom supplying it.

I understood at the time of sinking it, that the real object of his cofferdam was to lessen the pressure on the bottom of the caisson, under the fear that rock might be encountered on one side, with sand on the other, on reaching the bed rock, and that this might, without the buoyancy of the cofferdam, cause a tilting of the pier. My practice proved this was an idle fear. My east abutment caisson has a base of only 5,000 square feet, and that pier contains below the water line over 30,000 tons of masonry. My arrangement of air locks and air shafts enabled me to dispense with a cofferdam for it during the last ninety feet of its descent. As the masonry of the New York pier below water weighs less than 30,000 tons, and has a base of over 17,000 square feet, of course it would have more readily enabled the dam to be omitted, so far as danger of irregularity of bed rock is concerned. We are told in his letter that one of its purposes was to form a wharf around the tower; but at page 78 of his pamphlet the wharf idea, it seems, "was abandoned, owing to the necessity of strictly confining the expenditure of money to the bridge proper." We learn that another purpose of this dam was to protect the supply shafts and sand pipes which were outside the masonry. A glance at the horizontal section of the caisson will show that this method of protecting them, costing $50,000, was excessively expensive; for in addition to it, we are told on page 74 of his pamphlet that the caisson was surrounded by a wall of sheet piling six inches thick.

In view of the pending suit it is not the interest of Colonel Roebling's company, or of himself, to admit that any advantage whatever could result from using my improvements, and this may account for the variety of reasons given for retaining the dam. Colonel Roeb-

ling now, indeed, expresses an opinion of my air-lock design, not at all calculated to elevate it in the public estimation. When, however, one appropriates the property of another, and strives to avoid acknowledging the fact, or paying for the use of it, his views of its value are generally received with some grains of allowance. In this case the public will doubtless appreciate the humility with which, for two whole years (prior to the suit) he silently, not to say patiently, fathered this worthless design without a murmur. But patience cannot endure for ever, and now it is laid at the door of Cochrane, Bush, Pfaunmuller, Castor, and finally, my esteemed friend, F. E. Sickles, is made to father, at the last moment, "the practice of placing the lock entirely within the air chamber close to the bottom," which we are told "is one fraught with the greatest danger."

The Colonel says: "I intended to have placed the locks of the New York caisson entirely above the air chamber, but was deterred by the frightful waste of timber involved." After returning from St. Louis, however, he boldly adopted the practice "fraught with the greatest danger."

The distinguished inventor of the world-renowned "cut-off" doubtless knows the purpose of Colonel Roebling's eleventh-hour acknowledgment of obligations to him when he says, "I am equally indebted to Mr. F. E. Sickles, who was then sinking the cylinders of the Omaha Bridge in eighty feet or ninety feet of water with the air-lock at the bottom of them." Mr. Sickles can tell him that my design would be as unnecessary, and as needlessly expensive, if applied to a pneumatic cylinder, as would be an air pump to a non-condensing engine.

Any engineer knows that if the lock be located above the air chamber, although at the bottom of the air shaft, it must be entered from the top, and left through the bottom, and this alone precludes the convenience of side doors, and other important advantages resulting from my location of the locks, and which were admitted by hundreds of engineers who visited the air chambers of the St. Louis caissons. Owing to the vast difference in area of the chamber of a pile and that of a caisson (being as one to one or two hundred), these advantages, and the convenience of access, are of but little importance to the pile, but very great in the caisson.

It will not avail Colonel Roebling even to say that I simply did what in "the abstract" had occurred to others before. When my suit was commenced I was informed that one of his assistant engineers had been detailed to examine into all published records of similar devices, for the purpose of refuting my claim to novelty. The result of this research has been made public to a considerable extent already by himself, and to a greater degree in the legal answer to my suit, but so far nothing has come to my notice affecting either the validity of my air-lock patent, or that of the

pipes used so advantageously by him. No one has ever proposed in *the abstract* or in the concrete, so far as I know, to locate the air lock *within the air chamber*, either in pneumatic piles or caissons.

Colonel Roebling strives to make his readers believe that Pfaunmuller's abstract idea of placing the lock below water in the air shaft is all the same as placing it in the air chamber. Pfaunmuller's idea can scarcely be better understood from his own drawings than by reference to the accompanying Fig. 1, showing a section of half of the Brooklyn caisson. By comparing the location of the lock in that and in Figs. 2 and 3, the reader will see the difference in my location of it and that in the *abstract idea*.

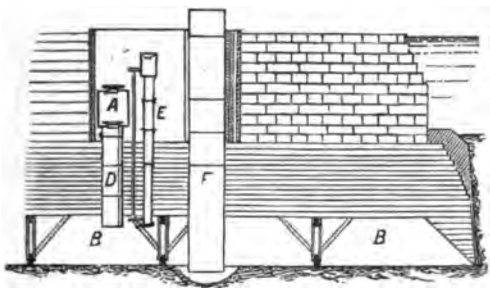


Fig. 1.

To show that ample opportunity was given Colonel Roebling to inform himself of all my designs, I will be pardoned for quoting from a very recent private communication received by me from one of the most distinguished American engineers, and which gave me the first notice of Colonel Roebling's recent letter. Speaking of this letter, this gentleman, who was in St. Louis at the time of Colonel Roebling's visit, says, "Two things in it surprised me—one was the severe personal remarks against you, the other the studied effort to detract from your merits as the inventor and designer of important improvements in the plan of construction and method of sinking plenum pneumatic caissons. . . . . Knowing as I did the pains you took to exhibit to him all your plans, to the minutest detail, and knowing that he had spent at least two days in critically examining the caissons and piers then being sunk. . . . I was struck particularly with the perfectly free and liberal manner in which you devoted your own time and attention to those gentlemen on the works and in the drafting office, in order to enable them to take full advantage of all the beautiful practical methods you had devised in connection with the caissons."

Colonel Roebling says that he designed the double locks of his New York caisson in May, 1870. This was after his visit to St. Louis, and

after mine were in the hands of the contractor. Fig. 2 is a section through the locks of the New York caisson ; Fig. 3 is a section through those in my east abutment. All of my caissons had the locks similarly located. No. 1 was designed *before*, and No. 2 *after* seeing my caissons. In the diagrams, A is the air lock, B the air chamber, C the sand pipes, D the air shaft, E the supply shaft, F the water shaft, and G the cofferdam.

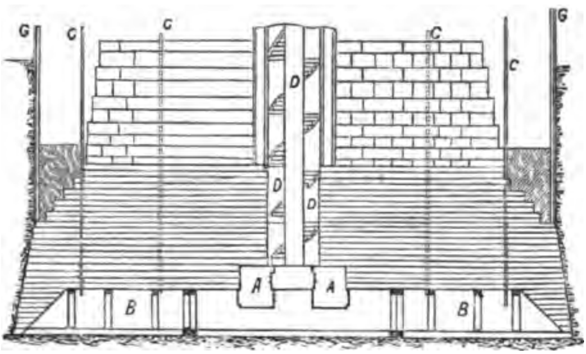


Fig. 2.

Colonel Roebling says, "I am compelled to state, however, in justice to myself, that in the arrangement of the New York caisson, I was not influenced in the slightest degree by the work of Captain Eads." If this be the case, the similarity in design of his caisson and mine must be recorded as the most remarkable *coincidence* in the history of civil engineering.

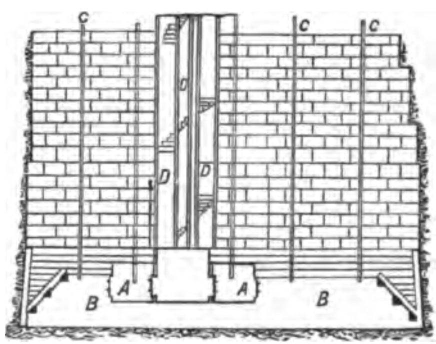


Fig. 3.

Colonel Roebling can only lessen the weight of testimony which the diagrams give against him by proving the prior existence of other designs containing any of the following features:

1. A masonry caisson (*or pneumatic pile*) with the air lock placed within the air chamber.

2. An open top water-tight air shaft within a masonry caisson (*or pneumatic pile*) to give access to the lock, and especially designed to obviate the necessity of an air-tight shaft and a water-tight envelope or cofferdam around the outside of the masonry.

3. The construction of such air shaft with wooden staves forming a vertical cylinder, as the most economic in material and workmanship.

4. The convenient circular stairway within said shaft.

5. The combination of small pipes with the air chamber, *outside of the air shafts*, to facilitate the discharge of excavated material.

I most cheerfully solicit for Colonel Roebling the aid of the entire engineering fraternity to discover in Christendom the prior existence of any one of these combinations and designs, all of which I claim were first suggested by me, and all of which were used by Colonel Roebling.

The water-tight curbs inclosing the air locks of the Brooklyn caisson were placed around them months after Colonel Roebling's visit to St. Louis, and were doubtless suggested by what he saw there. The locks and slender air-tight shafts indicate the intention of using the old method of upper air locks, to be taken off and replaced every time the sinking of the caisson necessitated inserting an additional section of shaft under them. The fact can doubtless be shown that this part of the work was too far advanced in the shops to justify copying my entire arrangement of air locks in that caisson also.

All credit of originality in these designs being studiously withheld from me by Colonel Roebling, proves to me the value of patent and copyright statutes.

In his pamphlet, at page 81, he states that the pipes (about fifty in number) were put into his caisson without the precise mode being determined as to how they were to be utilized. The maker of my sand pumps was addressed to know the cost of them, with a view, I suppose, of attaching them to these pipes. After learning that the pumps were patented, it was found that the most economic method in the world of discharging the sand was by blowing it out by the escape of air from the air chamber, through these pipes, which were not known to be also patented. This plan had been tried previously at Omaha by Mr. Sickles, and was abandoned because, as he informed me, he found it too expensive. At page 83 of the pamphlet, we are told of the tremendous velocity with which the material was carried out with this air blast, some of it to a height of 400 feet. This would indicate a prodigality of power; he, however, seems satisfied it is more economic than sand pumps, and I do not wish to controvert his opinion on the subject.

Colonel Roebling, with the greatest apparent sincerity, reproduces

what he terms "the harmless paragraph which roused the Captain's ire." Now he either did, or he did not know that he was not stating the fact when he asserted that the paragraph he reproduced in his letter, was the one that called forth my correction. He knew, or did not know, that he mutilated the paragraph by leaving out of it that which was most objectionable to me, and what, if true, would destroy the value of my air-lock patent, which he correctly defines as being "solely one of position in connection with a masonry caisson." By omitting the words "in masonry caissons" he withholds from his readers that which constituted the principal misstatement contained in his paragraph, and which, as it directly attacked the validity of one of my patents, justified me in promptly disproving all the statements in the paragraph by showing that neither Cochrane, Bush, or Pfaunmuller, had ever proposed to do what I did, viz., to place the air-lock *in the air chamber* "in masonry caissons." If he knew the paragraph was mutilated, the omission was clearly for the purpose of misleading the public, and unfairly placing me in the position of caviling at a harmless paragraph. If the omission was, however, unintentional, he will of course merit the charity of the whole engineering fraternity, for an engineer acting under the stimulus of the most honorable motives possible, who cannot correctly copy his own ideas, when comprised in the small limits of a single paragraph, cannot be morally responsible for unceremoniously appropriating the ideas of others.

The following is a true copy of the paragraph Colonel Roebling undertook to reproduce:

"The idea of placing the air lock at the bottom of the air shaft, below the water level, in place of above it, in masonry caissons, is not new, having been proposed in England as long ago as 1831 by Lord Cochrane, and again by William Bush, in 1841, and still later, in 1850, by G. Pfaunmuller, of Mayence. It nevertheless remained for Capt. Eads, in his St. Louis caissons, to make the first practical application of the same on a really large scale in this country."

Having compelled me, in defense of my own property, to publicly refute his published statements, he has now the effrontery to charge me with an attempt to manufacture public opinion!

Colonel Roebling evidently misunderstood my motive in not mentioning my suit against his company in my former letter. I did not do it because I thought that if it were shown that he had made misrepresentations respecting a matter where his professional reputation was even remotely concerned, and which was then awaiting judicial investigation, it would place him in the embarrassing position of endeavoring by unfounded statements to obtain a prejudgment of the case in court. This I had no desire to do. By alluding to it himself, however, and showing by his definition of the patent in question that he fully understands that patents are granted for new and use-

ful combinations, and that the air-lock patent he assailed was simply one of position *in connection with a masonry caisson*, he unwittingly proves what I had too much charity to expose.

In your journal of May 16th I exposed the errors in Colonel Roebling's "harmless paragraph," and have here pointed out at least half a dozen more misstatements in his letter. This I have done at considerable personal inconvenience, and feel that my time is too valuable for such employment; I hope, therefore, any additional asseverations he has to make in the premises will be reserved for the authoritative tribunal to which he has forced me to appeal. The solemnity of judicial procedure will insure more careful statements, and give to them a greater degree of public confidence.

Respectfully, etc.,

JAMES B. EADS.

St. Louis, August 8, 1873.

REVIEW

OF THE U. S. ENGINEERS' REPORT ON THE ST. LOUIS BRIDGE.

ENGINEER'S OFFICE ILLINOIS AND ST. LOUIS BRIDGE COMPANY, October, 1873.

To the President and Directors:

GENTLEMEN—The Report of a Board of United States Engineer Officers, dated September 11, 1873, approved by the Chief of Engineers, U. S. A., having been referred to me, I respectfully submit on these important papers the following review:

Owing to an inadvertence which occurred in the U. S. Bureau of Engineers when transmitting to this Company the above papers, it was stated that the Report had been approved by the Honorable Secretary of War. Fearing such high official sanction might possibly affect the credit of the Company, the Chairman of your Executive Committee and myself immediately visited Washington to obtain a recall of this approval until a review of the Report could be laid before the Department.

We learned from the Honorable Secretary that he had not approved the Report, and had taken no action on it, and a letter from the Chief of Engineers, addressed to the President of the Company, explained and corrected the inadvertence above mentioned.

The order convening the Board directs it "to examine the construction of the St. Louis and Illinois Bridge across the Mississippi river at St. Louis, and report whether the Bridge will prove a serious obstruction to the navigation of the river; and, if so, in what manner its construction can be modified."

I was informed by the Honorable Secretary of War that the Board was convened as "experts" to examine the subject, and was not required to take the opinion of others upon it. The Report, however, conveys, by its tenor, the evidence that the decision of its members was formed not alone on their own judgment as experts, but also upon the statement of a few of the steamboatmen examined. I was not present, but am reliably informed that the Board refused to receive the rebutting testimony of the Company, which, in consequence, has made complaint through its counsel to the War Department.

The Report declares that the Bridge will be a very serious obstruction to navigation when completed.

The correctness of this decision rests wholly upon the reliability of the testimony received by the Board, and the qualifications of its own members as experts in river navigation. For, manifestly, if the evidence relied on be untrustworthy, and the members themselves not qualified to act as experts, their opinions, although unanimous, and strengthened by the indorsement of the chief officer of their corps, can be of no value whatever. The views of the steamboatmen referred to in the Report are shown by the accompanying letters to be wholly incorrect. The first one of these letters is from the Mayor of St. Louis, Capt. Joseph Brown, who commanded several of the largest steamers on the river, and the second one is from a number of other well known, highly respected and skillful commanders, who have also navigated some of the largest steamers afloat. Several of these gentlemen are to-day deeply interested in the largest ones; hence they would be pecuniarily injured if the Bridge were really a serious obstruction. Not one of these gentlemen has a dollar of interest in the Bridge.

The height necessary for the pilot, and the difficulty of steering through the central part of the arch, are the only two questions on which the Board seemed to think it necessary to support its own views by reference to the assertions of steamboatmen. It will be hereafter seen by quotations from these letters that on these two points their statements were wholly unreliable. This fact established, it remains to examine what value should attach to the opinions of the distinguished experts themselves.

Webster defines an "expert" as "one who has skill, experience, or peculiar knowledge on certain subjects of inquiry in science, art, trade, or the like." I believe this definition is generally accepted as correct. The possession of either "skill" or "experience" in steam navigation on rivers can only be the result of individual practice, and as these gentlemen have not had this, it cannot be claimed that they have either skill or experience. Hence their qualifications must necessarily rest solely upon the possession of some "peculiar knowledge" of river navigation, and this, for the same reason, cannot be practical knowledge.

Their distinguished reputation would, however, lead the public to infer that they had carefully studied the various problems of river navigation, and that their superior scientific acquirements made the correct solution of these questions so simple that practical knowledge was unnecessary. It will be presently seen whether the views of the Board justify this inference. The opinions of purely scientific gentlemen on questions of commerce, navigation, and the like, must, when challenged, bear the crucial tests of experience, or they will fail to command public confidence. The Report declares:

"The apparently unreasonable height and size of the chimneys in general use on these steamboats are really essential to secure a good draft to the furnaces and economical combustion of fuel. Artificial means to procure the same end are generally very expensive, and often ineffective."

Nowhere has the economy of fuel been so closely studied as in the construction of ocean steamers. Artificial means are seldom used on them to produce a draft, and although the largest ones consume much more fuel per day than any Mississippi steamer, none of their chimneys approach the height of some of those on the river. The great development of power witnessed every day in locomotives, whose chimneys never exceed ten or twelve feet in length, is obtained without any artificial means to produce draft, except by the escapement of their waste steam. These facts completely disprove this first statement of the Board.

The Report says:

"Although it is a comparatively easy task to lower small chimneys, dealing with those of a large size is a very serious matter indeed. Their weight is so utterly disproportionate to their strength, even when new, that no machinery yet devised will enable large chimneys to be lowered, either wholly or in part, without very great labor and danger."

As it is well known to every one that it is more difficult to raise a thing than to lower it, the reader will wonder by what extraordinary means these formidable chimneys were ever erected, when it is so very difficult to let them down.

The second letter referred to above says:

"We have often raised and lowered them, and do not think, with such appliances (falls and derricks), that it is either dangerous or a very great labor. We believe $1,000 or $1,500 would pay for hinging the chimneys and providing improved appliances by which the largest chimneys in use could be readily lowered and raised."

This is the testimony of thirteen experienced steamboat captains, and it is sufficient to refute this second statement of the Board.

The entire weight of that part of the largest chimney which would require to be lowered is only three or four tons. If we assume the length of this part to be seventy feet above the hurricane deck, and seven feet in diameter, and made of No. 12 sheet-iron of a strength equal to 50,000 lbs. per square inch, a little calculation will show that such a cylinder, if well riveted, will, even after discounting 40 per cent. of its strength for the riveted joints, require over 300 tons to pull it asunder. Standing erect, it will sustain 60 tons with safety. If each end of such a chimney be provided with a strong angle iron flanch sufficient to preserve its circular form, and it be placed horizontally on rests at its ends, it will support a distributed load over its length equal to half a dozen such chimneys.

The size of chimney named is an extreme one, whilst the thickness is not unusual, nor is the tensile strength beyond that of good iron. A few of the simplest calculations that are made in the office of an engineer will suffice to disprove completely the third statement of the Board, to the effect that "their weight is so utterly disproportionate to their strength, even when new."

The Board enforces its opinion respecting the necessity of very high pilot-houses, by declaring that "experience has decided this point most clearly." This declaration loses all of its force when compared with the following simple statement made by the gentlemen just referred to, one of whom is the captain and part owner of the Richmond, which probably carries the highest pilot-house afloat. "In no case is it absolutely necessary for safety (in navigating the largest boats) for the pilot to be more than 35 or 40 feet above the water line." The fourth statement of the Board is thus shown to be fallacious.

On the assumption that a clear height of 50 feet above directrix is requisite for safe navigation, the Report says: "The horizontal chord of the center span, which lies 5 feet below the crown of the

arch, is 174 feet long, and gives the least width of water-way which seems compatible with safe navigation."

On this assumption it will be evident, presently, that the Board has understated the safe width at least fifty per centum.

The highest part of the boat remaining, when the chimneys are lowered, is the pilot-house. This, on large steamers, is usually surmounted with a pyramidal canopy or roof, the apex of which is of course safe anywhere within the 174 feet. As it is much higher than any other portion of the boat, it follows that when it is at either end of this distance, one-half the width of the steamer must be outside of this 174 feet, and yet in safety under the descending part of the arch—for the apex of this canopy is immediately over the keel of the boat. As the largest steamers are from 85 to 90 feet wide, it is evident that that much more should have been added by the Board to this 174 feet. Therefore, on its own data, this fifth statement, to-wit: that the least width compatible with safe navigation is only 174 feet, is also an error. It should have been stated at about 260 feet.

The Board having arbitrarily assumed 174 feet as the only width of water-way compatible with safe navigation afforded by an archway 520 feet wide, and 55 feet high, then endeavors to support the remarkable proposition that if the piers were placed at no greater distance than 174 feet apart, they would be "far preferable" if there were clear headway above. The arguments advanced in support of this novel opinion are equally as notable as the proposition itself. The Report says: "The reason given for this is that the piers would define the available width with exactness; they are easily seen and avoided." "In the case of a wide arch, however, the case is different. The piers are too far apart to be of service as guides, and lights placed on the structure will be so nearly overhead as to be of no great assistance." Even the possibility of hitting the piers when so close together does not lessen the superiority of the narrow gauge. In this event the Board offers the following consolation: "In case of striking the piers under headway, the damage done is to the hull alone; and even if so great as eventually to sink the boat, time will generally be afforded to save the lives of the crew and passengers;" whereas in case of a collision with the arch, the Board assumes that the upper works of the boat would be destroyed, and, "as the passengers are carried on the upper deck, such an accident would probably be attended with great loss of life." Further on we are told that "the steamboatmen deem a clear height of seventy-five feet above high water the least admissible"—a concurrence in which opinion doubtless actuated the Board in recommending the canal.

In these last few extracts there are three distinct assumptions, and these constitute the 7th, 8th and 9th errors on which the decision of the Board rests. These are as follows:

1. Lights placed on an arch fifty feet above high water are of no great assistance.
2. Greater head room for passing boats is indispensable.
3. Piers 520 feet apart are too wide to serve as guides.

From these three postulates, draw-bridges and narrow piers are absolutely necessary for safe navigation. If lights fifty feet high are "of no great assistance," surely they will be of no use at all seventy-five feet high; and if piers 520 feet apart are too wide to serve as guides, there would be no means left the bewildered navigator in approaching an opening 520 by 75 feet, but to run it by the compass, or by buoys placed in the channel.

The absurdity of this corollary proves that the three premises, of which it is a logical sequence, are incorrect.

The fact that all three of these assumptions are errors is fully established by the counter-statements in the letters referred to. In addition to this disproof, the following extract from the Report will show the fallacy of two of them, and prove conclusively that the Board itself believed it quite practicable for an arch fifty-five feet high to be effectively lighted, and its wide piers distinguished with certainty. The Report says:

"Whether this modification (the canal) be carried out or not, the Board deem it very important that such lights and marks should be displayed by the Bridge as will enable boats not only to distinguish the position of the piers and arches with certainty, but also to be able to tell the clear headway available under the Bridge."

Reasonable gentlemen would hardly wish to compel the Company to display lights to enable boats "to distinguish the position of the piers and arches with certainty," if they really believe "the piers are too far apart to be of service as guides, and lights on the structure will be so far overhead as to be of no great assistance." As the latter statement is completely refuted by the former one, I think its insertion in the report must have escaped the notice of the Board.

Another proof that the Board was not justified in declaring that the arch is too low, is shown by the following facts, which the Bridge Company was prevented from laying before the Board:

In the spring of 1866, several large meetings were held on 'Change in this city, by gentlemen interested in protecting the navigation of these rivers. Much discussion ensued as to the proper conditions to be imposed by law in bridging them. A memorial to Congress, presented at one of the meetings, was referred to a committee of the following fifteen gentlemen: J. S. McCune, J. F. Griffith, Barton Able, Joseph Brown, H. C. Moore, David White, J. H. Alexander,

Wm. M. McPherson, A. W. Fagin, Geo. Pegram, Adolphus Meier, Felix Coste, James Ward, N. Stevens and J. B. Eads.

On the 18th of April, 1866, this committee *unanimously* reported a series of resolutions, and from their report I quote the following:

"Your committee have carefully examined the subject with reference to ascertaining what restrictions are really demanded by the marine interests involved, and what can be conceded by those interests to such an extent as to leave no serious difficulties in the way of the requirements of the land transportation in crossing the river, and yet preserve a comparatively uninterrupted navigation on the Mississippi.

"The views of your committee are embodied in the following resolutions, the adoption of which they respectfully recommend:

"*Resolved*, That the delegation in Congress from Missouri be requested to procure, at an early day, the passage of a law to regulate the construction of bridges over the Mississippi River, and that they earnestly endeavor to incorporate the following provisions in said law:

"1. That all bridges crossing the Mississippi River shall have a clear height of fifty feet over the main channel, between the lower part of the bridge and high water mark, measured in the center of the greatest span.

"2. If below the mouth of the Missouri, they shall have one span of 600 feet, or two spans of 450 feet each, in the clear of abutments. * * *

"4. No draw-bridge, with a pivot or other form of draw, shall be permitted.

"*Resolved*, That a copy of this report and resolutions be sent to each member of the Senate and House of Representatives from Missouri at Washington."

These resolutions were *unanimously* adopted by the Exchange, and may, therefore, be taken as the authoritative expression of the largest and most influential body of merchants, shippers, and steamboatmen in the valley of the Mississippi. Among the fifteen names, are those of ten gentlemen directly interested in river navigation, and, with very few exceptions, these were all representative men in that interest.

In recommending such unusually long spans, the committee was informed at the time by me, that arches of such great length were entirely practicable, but that trusses increased in weight so rapidly in proportion to the span, that their great cost made them virtually impracticable. It was for this reason, and with a full knowledge of the fact, that in defining the height, the words "*measured in the center of the span*" were inserted by this committee.

These resolutions were published in the papers at the time, and everyone had, therefore, full notice of the height agreed upon, and that that height referred expressly to the *center* of the greatest span over the channel. After a company has during the last five years expended millions of dollars in constructing a bridge with spans greater and higher than those required in these resolutions, and with its plans publicly exposed on 'Change all the time, it is a remarkable fact that some of the gentlemen who were most influential in shaping the report of the committee in 1866 have been the most active in 1873 in obtaining from six eminent United States engineers an official declaration that the Bridge, whose dimensions they were chiefly instrumental in fixing, will, when completed, prove "a very serious obstruction to navigation." And this, too, after being prominently active in securing an official declaration from the Merchants' Exchange of St. Louis that these dimensions will "preserve a comparatively uninterrupted navigation on the Mississippi." This Exchange is composed of more than 1,000 members, a large number of whom are owners and captains of steamboats, whilst almost every one in it is more or less directly interested in preserving the navigation of the river. On such questions it can speak more intelligently than any other body in this valley.

It is no justification for the bad faith of these recalcitrant committeemen to say that the Exchange declared in 1873 that seventy-five feet in height was requisite for the safe navigation of the Mississippi. The Exchange did not, like them, ignore and repudiate in 1873 what it said in 1866. The height of seventy-five feet, as will be seen by the resolution of last May, applied only to bridges that may be built *below* St. Louis.

It will, on these facts, be conceded that it was an error of the Board to assume that greater height than is given by the center arch of this bridge is really necessary.

The tenth objection to the Bridge is because its arches make the following method of navigating bridge openings impracticable when descending the stream:

> "In case of wind, a boat can be dropped through the opening by lines made fast to ring-bolts in the pier itself." "The chance of dropping through along the pier is not available in this case, as the arch of the center span springs from a point about at the level of high water of 1844."

This method of navigating bridge openings, I think, originated with the Board, as it is not credited to any of the steamboatmen examined, and has not yet, I believe, been used on these rivers. I have never seen a steamboat, or other vessel, dropped down in a current by a line attached to a ring-bolt *below* her, and I think the laws of

gravity would prevent the success of the system, even if this Bridge had unlimited head room; but as the proposition seems seriously advanced by U. S. engineer officers of the highest rank, and as objection is made to the Bridge because the proposed system "is not available in this case," I have deemed it proper to question experienced navigators of the Mississippi on the subject. I quote the following reply from letter No. 2:

"As the face of the piers is only from one-fourth to one-sixth of the length of the large steamers, we don't know how such a thing is possible. Ring-bolts, to be useful in dropping a steamer, must be placed above the boat, not below her. To check the lower end of the boat, as it enters the opening, by fastening to ring-bolts in either pier, would simply result in having the upper end swing around broad side, and would probably wreck her on one of the piers. The upper end could not, of course, be controlled by ring-bolts 150 or 200 feet below it. In case of wind it would be still more impracticable."

From this it is evident that, without further explanation, the proposed system of ring-bolt navigation will meet with but little favor from the steamboatmen. On their testimony I feel justified in saying that this tenth statement of the Board is not sustained.

The Board thinks the steering through 174 feet of the center of the archway would be a matter of great uncertainty, but the testimony in the letters directly refutes this objection. Letter No. 2 declares on this point: "It would not be a matter of any difficulty. * * * Many of the channels through the difficult bars below St. Louis are not over 100 or 150 feet wide, and these are run by the largest boats either by buoys in them or by marks ashore." So much for the eleventh objection of the Board.

The Report says:

"They would moreover state that arched trusses, like those under construction, present so many difficulties to free navigation that, in future, their use should be prohibited in plans for bridges over navigable streams."

It is to be regretted that the Board was not more explicit in defining the "so many difficulties" before condemning the use of a form which often combines the highest economy with the most elegant and graceful proportions in architecture and engineering. Only two of these "many difficulties" are clearly indicated in the Report. One is that it prevents the proposed system of navigation by ring-bolts, and the other is the danger to life in case the upper works of the boat should come in contact with the arch.

The opinion of practical navigators, as set forth in the letters, seems to prove that ring-bolts would be useless, even if there were no arch to limit the head-room, and therefore the first objection falls to the ground. In the second one, the Board offers only the alternative of narrow piers and danger to the hull, *versus* wide arches and danger to the upper works. As practical navigators (see the second letter) assert that injury to the hull would be more dangerous than to the upper works, the second objection falls also. Under this evident diversity of sentiment between practical boatmen and the Board, it would seem advisable not to prohibit the use of arches until experience shall demonstrate what insuperable difficulties will really result here when this Bridge is completed. On almost every navigable river in Europe, arches are in use, and are passed without delay by steamers. It will be asserted that these steamers are much smaller than ours, but it may be answered that the arches under which they pass are also much smaller and lower. Certainly a large vessel can pass through a large one as safely and easily as a smaller one can through a small archway, if the relative proportions of the arches and vessels be the same.

The Report says of the proposed canal: "The steamboatmen have stated to the Board that they would be satisfied with this modification, and the engineers of the Bridge Company only raise as an objection the delay to trains caused by opening and shutting the draw."

I do not know what authority the Board had for thus committing me to a plan which, in my opinion, is impracticable and useless. No "bridge engineer" but myself is justified in speaking authoritatively on any proposed modification of this Bridge, and I was not addressed on the subject by a single member of the Board, nor in any way notified of its appointment or sitting. Col. Flad, who was temporarily in charge of the work during my absence, assures me that he gave no authority for any such statement, nor do I know of a "bridge engineer" who did. If consulted on the subject, I should have objected to the canal, for several reasons: First, it is absolutely unnecessary; second, it would delay the completion of the Bridge; third, it would be enormously expensive; fourth, it would destroy all of the wharf of East St. Louis alongside of the canal; fifth, it would ruin the landing for several hundred feet below the canal, by causing a deposit along the shore; sixth, it would involve a drawbridge, which would be inconvenient and dangerous, if ever opened; and seventh, it would mutilate the Bridge.

It has never been claimed that the Bridge will not, to some extent, prove an impediment to the free navigation of the river. A single pier can not be planted in its channel without involving increased

caution on the part of those who navigate it, nor can a structure be thrown across the stream which will not either limit the height of that which floats beneath it, or retard its progress until a draw be opened to let it pass. The right, however, of the traffic which flows east or west to cross the river is fully equal to that of the commerce on the river to go to the north or south. They are both common interests of the whole country, and the one can not be favored at the expense of the other without loss to the nation. Both intersect each other at St. Louis in such volume, that mutual concessions are imperative to insure the least delay to each other. These facts must be patent to the uneducated mind, and should not be ignored by gentlemen of intelligence, when sitting as experts in a matter where the question of what concessions should be made by each of these great interests really underlies the problem they were ordered to investigate. If they had no authority to consider this cardinal question, there was no necessity of convening so much ability, for it requires no great intelligence to discover that two piers standing in the main channel are an obstruction to navigation, and that the sides of an arch are too low to permit the passage of a craft as high as the crown of it. Yet this is really the sum total of the information given us by the Board. Such a result is no less unfortunate for the Board than for the Bridge Company. For the ability of its members in their legitimate profession, no one entertains a more profound respect than myself. The question of obstruction to navigation, however, is not an engineering one. It is one in which the judgment of experienced boatmen is of more value than that of the ablest engineers living. I cannot help regretting, therefore, that the Board thought its instructions did not require it to hear evidence in favor of, as well as complaints against, the Bridge.

Constrained by a sense of official duty not to seek for the testimony of experienced steamboatmen in favor of the Bridge, the Board was deprived of the intelligent and liberal opinions of such gentlemen as those whose views are herewith submitted, and the result is that it was unconsciously biased in its judgment while striving to discharge its duty conscientiously. The Report, therefore, reflects the absurd objections of the complainants, and some of those are set forth with an amount of superlatives which serves to make their fallacies still more prominent. Unreasonably high chimneys are declared "really essential for an economical combustion of fuel." Dealing with large ones is "a very serious matter indeed," because their weight is "so utterly disproportioned to their strength;" that they can not be let down "without very great danger and labor;" pilot houses can not be lowered, because "experience has decided most clearly" that they must be maintained too high for the arch; "great loss of life" will most probably occur if the upper works collide with the arch, but none is expected from the boat striking narrow piers;

ring-bolts cannot be used in dropping boats through; "the piers are too far apart to serve as guides; lights on the arch "will be of no great assistance," and therefore the Bridge is not simply declared an *obstruction*, nor even a *serious* obstruction, but "a *very* serious obstruction to navigation."

This recitation of difficulties and objections is greatly to be regretted for reasons beyond those which affect the Bridge; for when gentlemen of acknowledged technical ability are led, from any cause whatever, to utter opinions which experience disproves, or judgments which time will reverse, public confidence in the value of scientific acquirements is lessened, whereas their real worth, when legitimately applied, can scarcely be overestimated.

As a remedy for imaginary difficulties, the Board proposes to destroy the stone arches on the Illinois shore, and in their place to make a canal with a draw-bridge over it. One argument in favor of this scheme is as follows: "They (the Board) think, moreover, that it will only be in exceptional cases that boats will desire to pass through this draw, so the delay to trains from this cause will not be excessive." In this opinion I fully concur. I fail, however, to see the propriety of building such an expensive canal for such *exceptional cases*. This one argument alone is certainly sufficient to condemn the proposition it is intended to sustain.

The remarkable decision rendered against your Bridge, and the remedial canal proposed, will constitute one of the notable incidents connected with its history. If there be any who still think the structure will prove a very serious obstruction to navigation, the indulgence of a little patience from them must be asked until the completion of the work, and then the Bridge will vindicate the judgment of the St. Louis Merchants' Exchange, which officially fixed its dimensions in 1866, and secured from Congress an incorporation of them in the charter of the company, in strict conformity to which the Bridge is now being constructed.

Respectfully submitted,

James B. Eads,

Chief Engineer.

UPRIGHT ARCHED BRIDGES.

PAPER READ BEFORE THE AMERICAN SOCIETY OF CIVIL ENGINEERS, JUNE 10, 1874.

In a report on the Illinois and St. Louis Bridge, in 1868, I advanced the proposition that, for railroad purposes, an upright arched bridge could be more cheaply constructed than was possible by the suspension system. This postulate called forth, soon after, some dissenting views from engineering journals to which I had not, at the time, the leisure to reply.

In this paper I will endeavor to show that upright arched bridges can be more economically constructed than is possible by any other method whatever, no matter what length of span may be required. As the cost of the span (excepting the cost of roadway) will, by any system, increase at least as rapidly as the square of the distance spanned, the length of span will be limited, in all cases, by financial difficulties, before grave engineering ones are encountered.

I will first point out some of the disadvantages of the system adopted for the superstructure of the St. Louis Bridge, which was the best method of arch construction then known to me, and will respectfully venture to indicate such improvements as have suggested themselves, in consequence of these difficulties being so forcibly thrust upon my attention in the progress of that work. An earnest wish to make these and their remedies thoroughly understood will, I trust, excuse in me much that may seem commonplace or didactic.

In the St. Louis Bridge the upper and lower members, which constitute a single rib of the span, are tubular in form, the tubes being each 18 inches outside diameter. The rib thus formed is 12 feet deep from center to center of the tubes, and the two lines of tubing are braced together by a single triangular system of vertical bracing, formed of flat bars secured to the tubes at points about 12 feet distant from each other throughout the length of the rib, the bars being placed in pairs, one on each side of the tubes, and secured to them by pins passing through the ends of the bars and the couplings of the tubes. An upper and lower line of tubes thus braced constitutes one rib of an arch or span. The curve selected for the ribs was, for greater convenience of manufacture, the segment of a circle Each individual tube is straight, the curvature of the rib being ac-

complished at the junction of these individual members, each of which is about 12 feet long. The curve of the rib differs from a parabola but a few inches.

If the effects of temperature could be avoided, and the curve were a parabola, an equally distributed load on a rib would, of course, be borne by the upper and lower tubes equally, that is, half on each; and the only strain on the bracing would be in transferring half of the imposed load to the lower tube. In this case the tubes could be together and the bracing dispensed with. We should then have, in the two lines of tubes, the least possible section requisite to sustain this equally distributed load. To brace the arch against unequal loading, the tubes were placed 12 feet asunder.

The medium temperature was assumed at 60 deg. Fah. The effect of temperature (ranging from — 20 deg. to + 140 deg. Fah.) increases the length of the rib about 6 inches. This extension causes the crown to rise, which relieves the lower tube of compression at the abutments, and hence that tube does not then support any portion of the weight of the rib or the load. These are borne wholly by the upper tube at the abutments, and hence its section there must be increased accordingly. At the crown the strains are likewise changed. There, however, the *lower* tube does all the duty, as the upward bending of the rib relaxes the compression in the upper tube at this point, hence the lower one must be increased at the center of the rib to enable it to do this double service. It is thus seen that the upper tube at the abutments, and the lower one at the crown, must, when the temperature is at its maximum, perform the whole duty of sustaining the rib and its load. The strains in the respective tubes decrease from these points toward the haunches of the arch, where the centre of pressure passes through the middle of the rib. At the haunches the compression is borne in nearly equal portions by the upper and lower tubes. The extra section required by temperature, therefore, becomes smaller in the tubes as we leave the crown and abutments.

These are the effects of expansion. As the ribs are formed for a medium temperature, contraction by cold reverses these strains. The crown of the arch falls, and the *upper* tube at that point must be re-enforced, because it must then sustain the entire compressive strain, which, at medium temperature, is equally borne by both; while, at the abutments, the *lower* tubes have now to carry all the load. Thus it is seen that, both at the abutments and the crown, the upper and lower tubes must be each of greatly increased section on account of the changes of temperature.

These changes, in very extreme cases, will probably tend to withdraw the one tube or the other from the abutments, as extreme heat or cold affects the rib. At the suggestion of my chief assistant, Col. Flad, to give greater resistance to a change of form of the rib under

unequal loading, the skewbacks in which the tubes are fastened are rigidly held to the abutments by anchor bolts. Thus, at times, a tube at the abutments may not only be relieved of all compression, but may bear tension and pull upon its skewbacks, by which an additional compressive strain may be transferred through the braces to the other tube. For this contingency additional section had to be provided at the abutments in the first two or three tubes.

Greater depth of the rib would have increased all these strains of temperature, and would thus have involved larger sections at the crown and abutments. By lessening the depth, the strains would have been diminished, but a more flexible rib, under unequal loading, would have resulted. Between these evils on either hand, after various calculations, the most economic and satisfactory results were obtained with 12 feet depth of rib.

A diagram of the strains of the central arch, on which my remarks are based, is appended. (Fig. 25.) From these it will be seen that effects of temperature have compelled the use of a much larger quantity of metal in the ribs, than would have been necessary if these effects could have been avoided.

No one will, I think, deny that the cheapest possible form in which steel or iron can be used to span an opening and support an *equally* distributed load, is the catenary or suspended arch. It is equally evident that if an upright arch has the same span, weight, and curve of any given catenary, the strains in the one form would be no more intense than in the other. In the upright arch they would be compressive strains, and in the suspended arch they would be tensile ones. In the suspended form, the section of metal may be solid; in the upright, it must be hollow, tubular, or of some construction that will resist buckling; but to be of equal strength it must not necessarily be more weighty. If either form have an equally distributed load placed on it, no bracing will be requisite to preserve its normal curvature. The same load, if within the elastic limit of the metal, can be borne by either with the same amount of material. Hence, the only difference in material required for the two systems for any given span and load, must lie in the difference of bracing them to resist distortion when *unequally* loaded. I refer here simply to the span between the supporting towers in the one case and the abutments in the other. Between these points, with the same curvature, the sectional areas of each may be the same, under equal loads. In this I, of course, assume that the iron or steel can be trusted with equal strains in tension or compression. In compression, tubular or other sections are quite capable of sustaining, in wrought-iron or steel, all that it is safe to apply in tension if the lengths of the compressive members do not exceed eight or ten diameters. In the St. Louis Bridge, however, they are but eight diameters.

The section of arch is doubled by doubling the span, and in the

suspension cable it is evident that a long span involves equal sectional areas also in the shore spans, or portions between the towers and anchorages. Whereas, when the stream is spanned by a long arch, the need of such extra section in the shore spans does not exist, because they can almost always be short spans. Mr. Peter W. Barlow, C. E., in 1860, published a pamphlet on the Niagara Railway Suspension Bridge, from which I quote the following remarkably clear explanation of the fact, that in all known systems of girders, with any given depth, *four times* as much metal is required to obtain the same rigidity as is needed with the arch or the cable.

"Let *A C B*, Fig. 1, represent an arch supported on abutments *A* and *B*, and let the deflection produced by a given weight, loaded equally, be represented by unity. Now, let us consider the effect of making this arch into a self-supporting structure, or bowstring girder, by removing the abutments and substituting a tie, *A B*, Fig. 2.

"Assuming the same weight, w, to be placed equally all over, the deflection will be 2, the points *A* and *B* being no longer rigid, because the tie *A B* will extend as much as the arch *A C B* will compress. Therefore, to produce the same rigidity in a bowstring girder, four times the metal is required as compared with the arch. The same result arises in a cable *A C B*, suspended from the two fixed points *A B*, Fig. 3.

"If the back chains are removed, and a compression tube *A B* substituted, the metal is doubled, and you have a structure with only half the rigidity. The Chepstow Bridge, on the South Wales Railway, is an example of this arrangement.

"The mechanical combination in the Saltash Bridge is represented by substituting the arch *A D B* for the tie *A B*, Fig. 4, forming a combination of a suspension chain and an arch. The arch *A D C* will not perform the duty of compression unless it is connected with the chains by the ties *a a*, *a a*. When thus connected both the cables and the arch assist in supporting the weight of the load. The points *A B* now become fixed points, and as both the arch and the chains assist in supporting the weight, the deflection will only be half that of the simple suspension cable, with double the weight of metal. It therefore appears:

"1. To convert an arch, supported on two fixed abutments, into a bowstring girder, four times the metal is also required to support the the same weight with the same deflection.

"2. To convert a cable, suspended from two fixed points, into a Chepstow girder, four times the metal is required to support the same weight with the same deflection.

"3. To convert the same cable into a Saltash combination (which consists of a bowstring and Chepstow girder combined, so that the horizontal tie, in one case, neutralizes the compression tube in the other, by which they are both avoided), the deflection is reduced one-half, with double the weight of material; or, the same weight of material will produce the same deflection, with the same load, as in the case of the simple arch or cable. But this is obtained at the expense of double the depth; and if the arch or suspension cable was of the same depth as the Saltash, only one-quarter of the metal would produce the same stiffness.

"In the preceding illustration the bowstring and Saltash girders are referred to (parallel girders are more commonly used), but they

present no economy over the simple bowstring, and however perfect their arrangement and proportions, they will still require not less than four times the metal of a simple cable of the same depth and span to produce the same deflection."

Enough is shown by Mr. Barlow. in these extracts, to prove a far greater economy in the metallic arch, or catenary, than is possible with any truss system known. In practice, however, the chief causes which have conspired to lessen this evident economy are, (1) the bracing requisite to preserve the form of the arch when unequally loaded; (2) the effects of temperature, and (3) the necessity of heavier masonry to resist the pull of the cables or the thrust of the arch.

I cannot better illustrate the notably small amount of bracing or "girder power" required to resist the effects of unequal loading in the suspended arch or cable than by again quoting from the same distinguished author. Mr. Barlow says:

"If the beam *A B*, Fig. 5, be divided into two beams by being supported at *C*, the two half-beams, *A C* and *B C*, will deflect one-eighth of the amount of the entire beam *A B* with the same weight. Let us assume this to be a girder attached to a chain, and a load placed at *D*, the effect will be to distort it into the shape shown in Fig. 6. The deflection by the weight at *D* will cause a corresponding elevation at the point *E*, and the girder will assume the shape represented by dotted lines in the figure, to produce which a force equal to double that for a given deflection on half the beam is required, from which it is evident that the wave produced by a given weight at *D* will only amount to one-sixteenth of the deflection the same weight will produce on the entire beam resting on its two ends.

"In the above proposition it is assumed that the beam is supported at its centre point only; in practice, when attached to a suspension cable, it is supported at various points of its length, the difference between the wave of a supported girder and the deflection of an unsupported girder will therefore be greater than one-sixteenth.

"In order to arrive at the result by experiment, I had a model of the proposed Londonderry bridge, on a scale one thirty-third of the actual span, the length being 13 feet 6 inches between the bearings, a length exceeding that of the average of the models used by the Iron Commissioners in their experiments, and is amply sufficient—due allowance being made for the scale—to determine the accuracy of the deflections on the actual girder. The principal object of these experiments was to ascertain the deflection of the wave of a girder attached to a chain, as compared with the deflection of the same girder detached, which being obtained, it is perfectly easy to arrive at the deflection of the wave of any required suspension girder, because we have sufficient experiments on actual girders of various dimensions to obtain the deflection from a given load on the same girder not attached to a chain. These experiments gave a mean result of one twenty-fifth, so that, it being first determined what amount of deflection is to be the limit with a given load, in a given of bridge, you have only to arrive by calculation at the sections metal of a girder of the same depth which would deflect twenty-five times that amount."

The economy of a continuous girder, resting on a central support, depends upon the several supporting points remaining absolutely stable, or in line. The sinking of one, or the elevation of another, creates extra strains in the girder, which may destroy all the advantages of continuity. The great economy of girder power theoretically shown by Mr. Barlow is not attained in any suspension bridge of which I have knowledge, because the effects of temperature have not been avoided in their construction. The extension and contraction of the cables cause the central part of the girder to fall and rise, whilst the ends of the girder remain at a constant level. This is not avoided even where the towers are of iron also. Additional strains are thus created in the girder, for which increased sections are required. These strains can be avoided, however, by jointing the cables at the centre of the span, and cutting the girder in two at the same point. By this means each half-length of girder trusses the half-length of cable to which it is attached. If the end of each half-girder be securely fastened to the central joint, the economy of a continuous girder may be attained, because the effect of the load in bending the one-half girder down is resisted by the other, just as it would be if the two were continuous. The loaded one cannot deflect without distorting the cable above it, and the cable cannot deflect without rising where it is unloaded, which movement could only occur by bending up the unloaded half-girder beneath it. In this case the cable must be likewise jointed at the towers, as each half of its length is rendered rigid by its connection with the half-girder, and the half-girders must also be allowed to expand and contract at the towers.

Fig. 7 illustrates this method of eliminating the strains of temperature from the suspension bridge, and securing the fullest benefit of "girder power" with the greatest economy attainable by this system of bracing. If Fig. 7 be reversed, as in Fig. 8, the dotted lines will show that exactly the same economy of bracing, or "girder power," is attainable in the upright arch by this method, except that in one case the vertical connections act as *ties*, and in the other as *struts*, and inasmuch as the compressive strains on the long struts will necessitate greater sections than the tension strains require in the ties, a slight advantage is found in the suspended arch. Owing to the weight of the cables, this advantage will be increased by a difference in the expense of wind bracing. In this last item the difference will be found to be less, however, than is generally supposed.

This fact may be thus illustrated: If a column of metal be suspended by its upper end, its weight will resist the deflection caused by a current of wind that would blow it over if standing on its base. It must be remembered, however, that if suspended the resistance of the weight is only effective *after* the centre of gravity of the col-

umn has been moved. When vertical its resistance is *nil*, the maximum effect being exerted when the horizontal position is reached by the column. Therefore, to preserve the lower end absolutely from movement by the wind would require as strong a brace or guy as would be needed to preserve the same stability at the upper end if the column were standing. The case is identically the same in the suspended and upright arches. The bridge should be braced against all movement by wind, as far as possible, and hence the stability of the cables due to their weight will not, on investigation, be found to possess as much importance as has been claimed for it. The plan of spreading the arch at its bases, as proposed by Telford in his 600-feet span for the Thames, has been applied in its reverse form to the suspension bridge as a means of securing greater stability against wind pressure. Either application of this feature, suspended or upright, involves the necessity of increased section in the cable or arch, the supporting power of either being lessened as the plane of the curve inclines from the vertical. The increased section therefore involved in this means of securing stability should be charged in the estimate of wind bracing.

The illustration I have given of the suspended and standing column may likewise be referred to here, to show that for rigid structures the weight of the cables in preserving the suspension bridge from a change of form under unequal loading is not an element of so much importance as advocates of that system claim. Let *A B*, Fig. 9, be a suspended arch, loaded at *D*, and *C* be the point to which the greatest curvature has been removed by the load from the centre, *E*, of the span where it was when the cable was in equilibrium. By reversing the figure we see at once that in the upright arch the flattening from *A* to *C* increases the thrust of that portion against the remainder of the arch, which, being without load and of inferior weight, can only be sustained by the strength of its bracing or girder power. This change of form in the arch lessens its ability to resist the effect of the load, and even increases the power of the weight to further distort it, by the additional horizontal pressure against the portion *C B*, due to the flattening of *A C*, whilst the curvature of *C B* becomes less favorable for resisting this horizontal pressure. In the cable these conditions are exactly reversed. The effect of gravity upon the flattened portion tends to resist a further distortion of the catenary. The tensile strains in this portion increase with the straightening between *A* and *C*, and thus equilibrate the effects of the load at D.

If we apply the illustration of the column in explaining these phenomena, we see that if a force shall have *already* deflected the suspended column, the application of a load to its lower end will tend to restore its vertical position, and will lessen the strain on any horizontal brace or guy employed to resist the deflecting force; but

if the column be placed on end and deflected, the imposition of an additional load upon its upper end will tend to overthrow it, and will increase the strain on the brace or guy resisting the deflection. These effects are precisely the same with the arch when suspended and upright.

If we desire to prevent any appreciable deflection of the suspended column from its normal, or vertical position, it is evident that we must apply the same amount of horizontal bracing to resist the deflecting force, that would be required to preserve the column vertically against the same force if the column were standing on its end; for, so long as the suspended column remains vertical, the resistance due to its weight, or that of the load, is *nil*, as before stated; and so long as its vertical position is maintained when standing on end, its own weight cannot be added to the deflecting force, and hence it will need no more bracing than if suspended. It is *after* distortion has occurred that the effect of the weight of the cable or the arch is felt; in one case to restore equilibrium, and in the other to increase its disturbance.

For railroad purposes, as well as to insure durability in the structure, this distortion should be prevented as far as possible, and I have no doubt, with a proper degree of stiffness in the roadway of both systems, the bracing of the upright arch can be quite as economically accomplished as that of the suspension cable. Just in proportion, however, as we permit greater undulations in the roadway of the bridge, the economy of bracing will incline in favor of the suspension system.

Recurring to Fig. 8: if half the span of the upright arch be loaded, a horizontal impulse is given to the arch at the crown, tending to move its central point toward the unloaded half. To prevent this horizontal movement of the centre of the arch is one of the most important problems with which we are dealing. If the unloaded half be kept from curving upward, the movement of the centre horizontally cannot occur, and then the undulation of the roadway will be reduced to the minimum. Evidently the slightest bending of the girder will result in a horizontal movement of the centre of the arch, and cause a wave in the roadway, hence depth of girder is an important element in stiffening the arch. This movement naturally suggests as an expedient that the ends of the lower chord of the girder be firmly fixed to the masonry, by which means one-half of the girder would resist this movement by tension, and the other half by compression, which would certainly reduce the wave. But owing to the effects of temperature, the ends of the girder, at the abutments, must be left free to move horizontally, or they will push or pull the masonry, to its injury or destruction.

Another effect will be noticed as a result of the load being on half of the span (see Fig. 8). The top chord of the loaded girder, as well

as the arch itself, is in compression, whilst the lower chord acts in tension to resist the thrust from the upper chord; therefore, on this side we have two longitudinal compressive members, and as these strains are reversed in the unloaded half, we find two similar tension members there. It is evident that if the struts were run up to the upper chord, and tension diagonals were introduced from the top of the first strut, at the chord, to the bottom of the second one, at the arch, and so on to the centre, the arch would supply the tensional resistance for the upper chord, and the lower one could be dispensed with in the loaded side, and the tension chord in the other half. This modification simply substitutes spandrel bracing for the girder, and, when jointed at the crown, forms the system used in the jointed arch bridge at Szegedin. From an examination of Fig. 10, which is a skeleton drawing of that bridge, the strains of the various members of one of its ribs will be seen, as given by M. Ritter, from whose work the drawing is copied.

The resistance to deflection by this and the preceding form of bracing would evidently be increased by greater depth of girder. In the Szegedin bridge the large sections of the braces and chords near the centre of the structure are due mainly to the shallow depth of the rib, while this depth has evidently been kept shallow because of the increased length required for the struts and braces. These being alternately in compression as well as tension, are by economy limited in length. The span of the bridge is but 135 feet. In a structure of 400 or 500 feet length of span these members would be of great length, and hence the advantage of depth would be lost by its greater proportionate cost.

The half-girder system of stiffening the arch will be found more economic than any method of spandrel bracing, because vertical members only are required between the arch and half-girder, whilst greater proportionate depth is practicable without involving such long compression members. But, for another important reason, greater economy and greater rigidity can be attained by it than by spandrel bracing. In resisting the horizontal movement at the central joint by spandrel bracing, the diagram of the Szegedin bridge shows that the chord over the unloaded half-arch acts wholly in tension. Its large sections in the central panels of the half-rib, being about one-third of those of the arch, indicate the great pull brought by it upon the unloaded half-arch, while stiffening it to resist the buckling impulse from the loaded one. This pull increases the compression in the unloaded arch, and thus increases the tendency in the central joint to move toward the unloaded side of the structure. When it is remembered that the deflection of the loaded half depends almost wholly on the horizontal movement of the central joint, it will be evident that any system of bracing which, while tending to stiffen the arch increases the impulse to move its centre

in the direction of the unloaded half-span, must be in conflict with economy, at least in theory if not in practice. As the loaded half produces compressive strains at the same time in the chord over it, and these, by the braces at the central joint, also tend to increase its horizontal movement in the same direction, resistance to these strains can only be had by increased material. These objections do not exist in the girder system, whilst all spandrel braced arches are open to them, whether jointed or not. Therefore spandrel bracing will invariably prove more expensive, theoretically, than girder bracing, for the arch.

If the chords in the spandrel bracing referred to be placed *beneath* instead of *over* the arch, as in Fig. 11, these objections vanish, because the strains are reversed. Under the loaded half they become tensile strains and resist the horizontal movement at the central joint by pulling directly against it, and this serves to prevent the spread or flattening of that half. By a system of struts, between this member and the arch above it, the chord becomes virtually a suspension cable, and acts in unison with the arch to sustain the load, in the manner of the Saltash girder.

This brings us at once to the most economic solution of the problem, of preventing the horizontal movement of the center of the arch, and as a sequence, to the most economic system of superstructure that is possible.

If we examine the effect of this arrangement on the unloaded side of the span, we find the chord here has become a compressive member, and also resists the horizontal force at the crown. The intermediate strutwork acts in tension and prevents the rising of the unloaded arch, as well as the fall of the chord. Exactly such strains in tension as are borne by the loaded chord will be the sum of those borne by the unloaded one in compression. On the unloaded side, the arch and its chord or counter-arch act simply as a strut to transmit the horizontal and vertical forces at the central joint directly to the abutment at the unloaded side. The necessity of preventing, as far as possible by any method of bracing the arch, any horizontal movement at the crown, should not be lost sight of, as it is of the first importance in insuring rigidity. By no method can this be so economically accomplished as by the counter or inverted arches shown in Figs. 14 and 15, which give also diagrams of strains of a 500 foot span on this plan.

By reference to these diagrams it will be seen that a notable uniformity of section is obtained in all of the members of the structure, a circumstance very favorable in construction. Perhaps the most remarkable result, however, that is developed by the diagrams will be the fact that with a steel arch, with maximum compressive strains of 20,000 pounds per square inch, and all the other members of wrought iron with 10,000 pounds maximum strains per square inch,

and with 10 per cent. added for joints, it is practicable to sustain on a 500 feet span a moving load of 2,500 pounds per linear foot by a superstructure weighing (including rails, floor bed, and everything) only 1,500 lbs. per foot.*

This remarkable result is due—

1. To the fact that every strain from temperature is completely eliminated.

2. By combining the arch and cable, great depth of girder or bracing is obtained.

3. No struts longer than one-half the versed sine of the arch are required, and but few that long.

4. No great strains, such as are incident in almost every other system, are thrown on the struts. When the roadway is suspended beneath the arch as in the case of the diagrams of strains (Figs. 14 and 15), the compression on the struts is much reduced.

5. Long struts being unnecessary, a greater versed sine or more economic depth of arch is practicable.

6. The least disturbance of equilibrium brings every member of the structure into play to resist it.

I will not stop to compare the relative economy of this method of stiffening an arch, with that of any girder system as at present applied to suspension bridges, but will call attention to some of the facts disclosed by the diagram.

To span an opening 500 feet long with a bowstring girder, and attain equal stiffness, would involve, as is shown by Mr. Barlow, the use of four times as much metal as the arch would require. The average strains in the arch in the diagram equal 1060.6 tons of 2,000 pounds; hence a bowstring girder would involve four times as much, and would require an average sectional area in its two members equal to the resistance of 4,242.4 tons. To stiffen the arch in the diagram, an average section in the counter-arch is required equal to the resistance of 184.8 tons, or about $\frac{1}{23}$ part of the weight of the bowstring girder. Mr. Barlow obtained by his experiments with models a result of $\frac{1}{25}$ as the weight of his stiffening girder. The similarity of his experimental results with those of the careful scientific deductions shown in the diagram seem to me quite remarkable. It will be observed that his proposition as to the necessity of quadruplicating the weight of the girder to get the stiffness of the arch relates to the sustaining members only, and omits the bracing or web needed in all girders between the upper and lower chords. In his experiments this was of course included.

Respecting the relative strength required in a stiffening girder for

* The correctness of this statement has been ascertained by carefully estimating the weights of the span from detail designs, and calculating the strains induced by the weight of the structure and its variously proportioned loads.

a suspension bridge, as compared with the strength of a girder for the same span suited to bear a uniform load of the same intensity, Rankin says (in a note, page 375, "Applied Mechanics," 5th edition):

"Hence, it appears that if the chain be supposed inextensible, the proportion borne by the strength of the stiffening girder to that of a simple girder of the same span, suited to bear a uniform load of the same intensity with the traveling load, ought to be as 0.138 to 1; while if the chain is supposed very extensible, as in the approximate solution, that it is found to be $\frac{1}{27}$, or 0.148 to 1; so that in the intermediate cases that occur in practice, no material error will be committed if that proportion be made as 1 to 7 or as 0.143 to 1."

The wide difference between the proportion of $\frac{1}{28}$ obtained experimentally by Mr. Barlow, and the $\frac{1}{7}$ mathematically deduced by Prof. Rankin, arises chiefly from the fact that the one relates to *stiffness*, while the other refers to *strength*. Mr. Barlow's illustration shows that, with double the metal and the same load, the deflection of the bowstring will be twice as great as that of the arch; but as the strains would not be increased thereby, it follows that double the metal in the girder should (theoretically) give the same strength of the arch, whilst four times the metal is required to give the same stiffness. After making this allowance, however, the proportions of Prof. Rankin are nearly twice as great as those of Mr. Barlow. This may arise from difference in the assumed proportions of depth and length of girder and chain on which the Professor's calculations were based, and those of Mr. Barlow's models.

Leaving this discrepancy to be explained by others, I will point to the fact that by the diagram the average strains in the counter-arches are only 184.8 tons of 2,000 pounds, while those in the arch are 1060.6, or 5¾ times as great. Hence, as it requires at least twice the metal of the arch to convert it into a bowstring girder of equal strength, it will be seen that the girder would weigh 11½ times as much as the counter-arches by which the proposed arch is stiffened, or 65 per cent. less than the weight of stiffening girder required for the suspension bridge, according to Rankin. While the stiffness of the arch over that of the bowstring girder is maintained under the whole load, the form and depth of the counter-arches give far greater resistance to undulation under the movement of partial loads than is possible by any practicable depth of stiffening girder yet proposed for a suspension bridge.

I am confident that a careful investigation of the system suggested and the facts stated will convince those interested that it is entirely practicable to brace the upright arch more effectually and with equal, if not greater, economy than is possible by any known method of stiffening suspension bridges; and that the proposed system avoids all the disadvantages resulting from temperature. These two difficulties have hitherto prevented the most perfect economy of super-

structure from being attained. By overcoming them, the cost for long spans is wonderfully reduced, compared with the most economic truss systems yet devised. By any method of girder construction hitherto known, it is impossible to span a clear opening of 500 feet with less than three times the dead weight of the arch on the proposed system, with equal strength of girder and with the same material and allowable strain. More than twice the quantity would be requisite in any case; but when the span becomes so great, a less economic depth of truss must be taken, and the length of truss must considerably exceed that of the arch, because the girder must rest upon the masonry, whilst the arch rests against it. In addition to this great excess in its cost, the girder will have twice the deflection of the arch under equal loads.

The arch, as hitherto constructed, being still much cheaper for the superstructure, it is evident that a great saving in the substructure must have existed in the girder systems, to enable them to be introduced during the last thirty years in all parts of the world, almost to the exclusion of the arch. The difficulty of stiffening the arch, and the inconvenient effects of temperature, together with the greater cost of masonry, have given the different girder systems a degree of public favor which must disappear when these objections to the arch are removed.

Having shown how the cost of the arch in superstructure may be brought to the lowest possible point, by economic and effective bracing and by the avoidance of the effects of temperature, I will proceed to suggest such methods as will in almost every case render, in combination with the arch, the economy of the girder *substructure* available. Evidently if the cheapest possible form of superstructure can be combined with the cheapest methods of substructure, we shall have attained the most economic system of construction that is possible.

The greater masonry required for the arch arises solely from the horizontal forces resulting from the weight of the arched span and its load, and from those which are induced by temperature. By reducing the weight of bracing to a minimum, and by eliminating the strains of temperature, we not only arrive at the greatest possible economy of superstructure, but by thus lessening the horizontal pressure upon the masonry to the lowest possible point, we also reduce the cost of the substructure to a minimum, so far as the arch *per se* is concerned. Therefore, to reduce still more the cost of masonry, and approximate, if not equal, the economy of girder bridges in this item, we start from an already advanced point in our problem.

Where timber is abundant, an economic method of saving masonry in the piers of arched bridges may be employed where the bridge consists of two or more arches, by introducing wooden chords in them against the skewbacks or piers and abutments. These wooden

chords would act in compression only, and form a series of *compression* members instead of a line of *tension* members or chords from abutment to abutment, as in the case of bowstring girders. They need not, however, be in compression unless the bridge is loaded. If there be a series of long spans together, however, the loading of an arch at one end of the series would produce compression throughout the entire line of chords in the other arches, and this might shorten those chords so much in the aggregate as possibly to allow the loaded arch to spread too much, and thus produce objectionable deflection in the roadway of that arch. In this case it would be desirable to make the abutments stronger, and put an initial compressive strain in all of the chords of the system by means of screws or wedges against one end of each line of chord timbers.

In a series, for instance, of five arches of 500 feet span each, where the maximum horizontal force of the load is 500 tons on the chords if an initial compressive strain of 400 tons be produced in the entire system, from abutment to abutment, when the bridge is unloaded, then this initial strain will be taken out of the chords of the first arch so soon as it has its maximum load on it, while the compression in those of the unloaded ones will be only increased 100 tons, and therefore the shortening of those chords would only be one-fifth part as great as if they had no initial compression; hence the deflection by load on any one arch in the system would be reduced accordingly, and would be really less than what it would be in an ordinary bowstring girder. In this case, the maximum stress on the abutments, when all the arches are loaded, would be 500 tons load + 400 tons, initial compression + (the force from unloaded arches say) 300 tons making a total of 1,200 tons; while the piers would be subjected to vertical pressure only, and hence they could be as cheap as if for ordinary girders.

If the timbers were secured together to resist tension, of course the compressive strains would be so much lessened, and the abutments proportionately reduced in cost. With such a system of wooden chords used only in compression, the repairs of the timber would be very simple and easy. The sticks should be squared at each end and butted against each other throughout the span, vertical movement being prevented by the connections of the floor beams with the arch, and lateral movement by the wind bracing of the floor. To remove any defective stick it would only be necessary to withdraw the wedge, or slack the screw at the end of the line in which it was located, and by which the initial compression was created, and every piece in that line would then be released and any one easily removed.

The initial compression could be so great that no tension could be produced in either chord by wind pressure, and hence no jointing of the sticks together would be necessary to resist wind.

The track stringers and every longitudinal timber in the floor-way could be thus utilized to resist the thrust of the arches, and in this way, where timber is cheap, a very durable and economic structure can be erected. As no thrust in such a bridge can come on anything but the abutments, and as these can generally be located on the high banks of the stream, the cost of the entire substructure would exceed very slightly that which would be required in a truss bridge with spans of equal length. It would probably be best to make the arches of such a series uniform. The thrust at the abutments will be the same, whether there be but one or many arches in the system. The stress on the chords (except initial) would be due entirely to the unequal loading of the various arches.

This method is applicable to parallel truss bridges, and by it the iron lower chord or tension member may be omitted and wooden compression members substituted therefor. The objection to the combination of wood and iron in bridge construction, owing to the difficulty of repairing the bridge, does not exist in this method. In all others, the wood is either under tension or compression, and therefore difficult to be removed. In this, the entire chords of any one arch could be removed without endangering the stability of that arch or of any other one of the series; for it is plain that, if any temporary weight were placed on the floor beams, which would equal the weight of the chords to be removed, the equilibrium of the whole series would be undisturbed by their removal, so long as the whole bridge remained unloaded. In repairing, it would never be necessary, however, to remove any one chord entire at once, but only to replace such pieces as were found defective.

Where the use of timber is found objectioneble, the cost of masonry in arched bridges may be greatly reduced by the following method also. Suppose *A B*, Fig. 2, be a bowstring girder, whose arch produces a horizontal force of 500 tons; and that the load increases this force to 1,000 tons. The iron chords of such a girder will require a sectional area of 200 inches if we allow a strain of 5 tons per square inch. Suppose two such girders, Fig. 11, constitute a bridge with abutments capable of resisting a horizontal force of 1,000 tons, and that each arch abuts against the other at the central pier, then it is evident that the section of the chords may be at once reduced one-half, or to 100 square inches; for the thrust of one arch will balance that of the other, and the only strain which can come on the chords of either will be from the effect of the load, and this can not exceed 500 tons. No horizontal strain can come on the central pier, for any unbalanced thrust will be borne by the chords. If both arches be equally loaded, or both be unloaded, no strain whatever will be on the chords of either.

If the arch *A* has its maximum load imposed, its chords will be strained in tension to 500 tons, but if the chords of both arches be

formed to resist compression as well as tension, 250 tons of this strain will be transferred in compression to the chords of *B*, and by it to the abutment of *B*, while the tension in the chord of the loaded arch will be reduced to 250 tons. Instead of a central pier which would have to sustain a horizontal force of 500 tons if no chords were used, we now have a pier subjected to vertical pressure only; and instead of bowstring girders, with chords of 200 square inch section, we need only one-fourth of that. As the chords of a bowstring girder are in great part supported by the arches, if we can reduce the chords 75 per cent., we at the same time lessen the requisite section of the arch itself, by relieving it of this much dead weight.

The only difficulty in carrying out this suggestion is the expansion and contraction of the chords by heat and cold. Suppose that to the end *A* of the lever *A B*, Fig. 12, we attach one end of the chord *C* of one arch, and to the end *B* we attach one end of the chord *D* of the other arch, and that the fulcrum *E* be secured to the central pier, whilst the other ends of the chords are attached to the abutment ends of the two arches. Now, if the inner ends of the arches be made to abut against the fulcrum of the lever, it is evident that the two chords may expand or contract without moving the central pier, or in any manner disturbing the arches. Such expansion or contraction of the chords will simply cause the lever to turn upon its fulcrum. A force against the fulcrum from either side of it will not, however, tend to turn the lever at all. Such force would be resisted equally by both chords, one in tension and the other in compression. One-half of the force—500 tons due to the load on one arch—acting in the direction of the arrow, would be received on *C* in compression, and one-half on *D* in tension, whilst the only movement of the lever or fulcrum would be that due to the stress on *C* and the tension on *D*. The lever could be made in the form of two circular disks fitted in circular rests in the skew-backs, the axes of the disks being coincident. The end of the chord from one arch would be fastened between these disks by a suitable pin passed through that chord and the upper part of the disks, and the other chord would be fastened by a similar pin through it and the lower part of the disks. The effect of heat or cold on the chords would simply cause a rotation of the disks in their rests without strain and with no horizontal movement of them or the skew-backs. This lever arrangement is illustrated by Fig. 13, which shows a skewback in perspective, seated on a series of rollers resting on the cap-plates of the pier. The object of the rollers is to avoid any possibility of horizontal strain on the pier, arising from the extension of one set of chords and the compression of the other in two adjacent spans, when the load on one span is greater than that on the other. This movement will be so slight, however, in spans of ordinary length, that if the central pier were proportionately high, the rollers would be unnecessary.

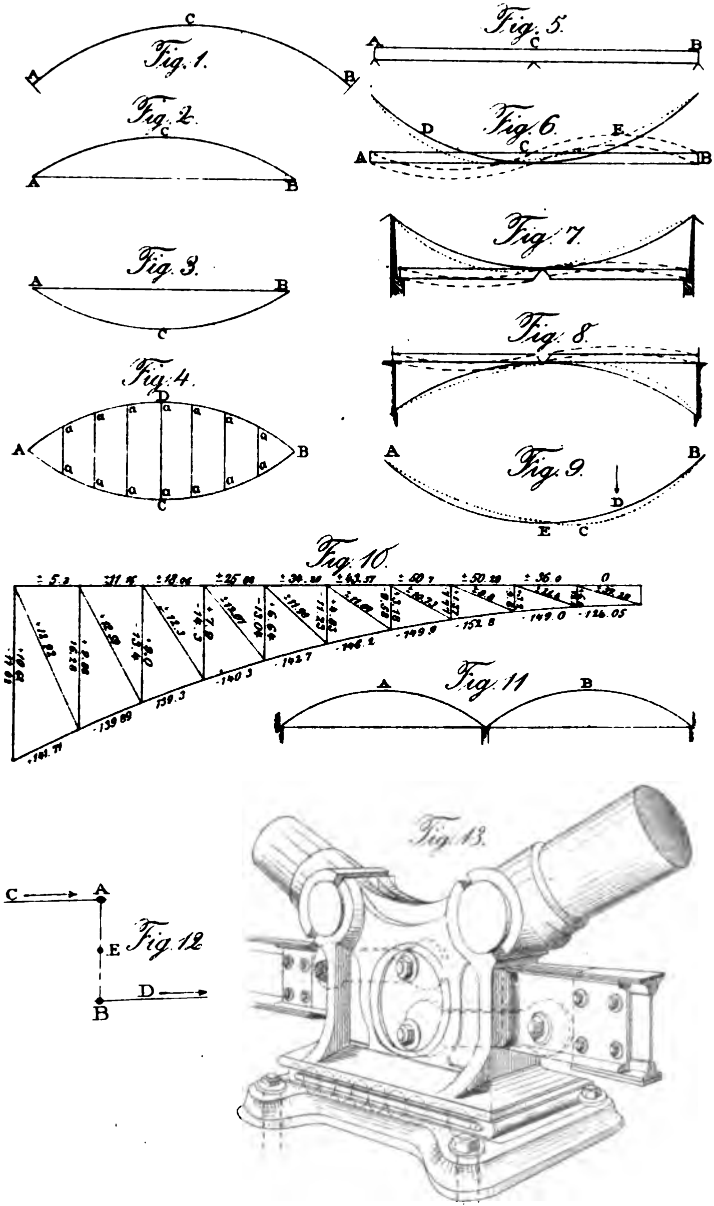


Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
Fig. 7.
Fig. 8.
Fig. 9.
Fig. 10.
Fig. 11
Fig. 12
Fig. 13.

The chords of the arches are, in Fig. 13, attached to the disks by links pivoted to them. One end of a link is inserted between the two disks, and a pin is passed through its end and through the two disks *above* the centre of the disks, while the link from the other chord is similarly secured by a pin passed through the disks and link *below* the centre of the disks. The other ends of the link are pivoted to the adjacent chords of the two arches. This, in effect, constitutes a vertical lever attachment for the ends of the chords, of greatly stronger design and more compact than would be possible with a vertical lever having a central fulcrum pin through it. The links must, of course, bear compression as well as tension.

This plan of disks is best used in two-span designs, but can be used with great economy in those of but one, or of more than two spans.

When both arches of a two-span bridge are loaded, the abutments will of course receive as much thrust as with an ordinary arch, for the chords are only strained when a greater load is on one arch than the other. But the central pier has nothing but vertical pressure on it, and may be greatly reduced in cost, while the chords are only one-quarter the weight that would be needed in ordinary bowstring girders. If four spans be desired, the central pier need then only be strong enough to resist the thrust due to unequal loads on the arches, as the thrust from the dead weight of the arch on one side of it will be balanced by that of the one on the other side of it.

In the case of a single arch, let us suppose that one end rests upon one abutment capable of holding but half the thrust of the arch, and at the other abutment we locate a skewback, designed substantially as in Fig. 13. Let a chord be secured to the end of the arch at the first abutment, and to the inner link at the other abutment. Now, if the end of the second link be secured in this abutment so as to resist compression, it will throw against this abutment one-half of the thrust of the arch, while the chord will receive the other half in tension. By such a modification one-half the weight of the chord of an ordinary bowstring girder and one-half of the masonry that an ordinary arch would require will suffice. The skew-back with the disks in it would have to move on rollers in this case, and would make one-half of such movement as would be due to the elongation of the chord from temperature and from the load also. By very simple modifications of the system this movement could be divided so as to occur equally at both abutments. This movement would, however, be no more objectionable than that of the ordinary iron girders on their piers, while the deflection, by preventing the arch from spreading, would be 25 per cent. less with a single arch, and 50 per cent. less if two arches are used, than with any girder bridge of equal depth and strength now known.

By combining with this modification of the bowstring girder, the counter-arch method of bracing the arch, before suggested, and with

central and abutment joints in the arch, we have a system of bridge construction from which the effects of temperature are absolutely eliminated, and which will be found to greatly surpass in economy of superstructure anything yet devised, and which admits of such reduced cost of substructure as to almost, if not quite, equal that applied to the various kinds of girder bridges.

The construction of the arches in half-length ribs, with the counter-arch bracing, enables the ribs to be easily erected, even if the spans be enormous in length. Each segment or half of a rib could be easily erected by a temporary tower placed in the stream, midway in the span, either on floats or piles, to support the inner ends of the segments, and on this, and on the abutments, should be placed machinery sufficient to lift a segment. When it is understood that such a segment, with its counter-arch and bracing for a span of 500 feet to carry 2,500 pounds per linear foot, weighs less than 50 tons, if the arch be of steel, and that the hoisting machinery needs only to lift each end of such a segment, or 25 tons, the ease with which such arches can be put together will be at once manifest.

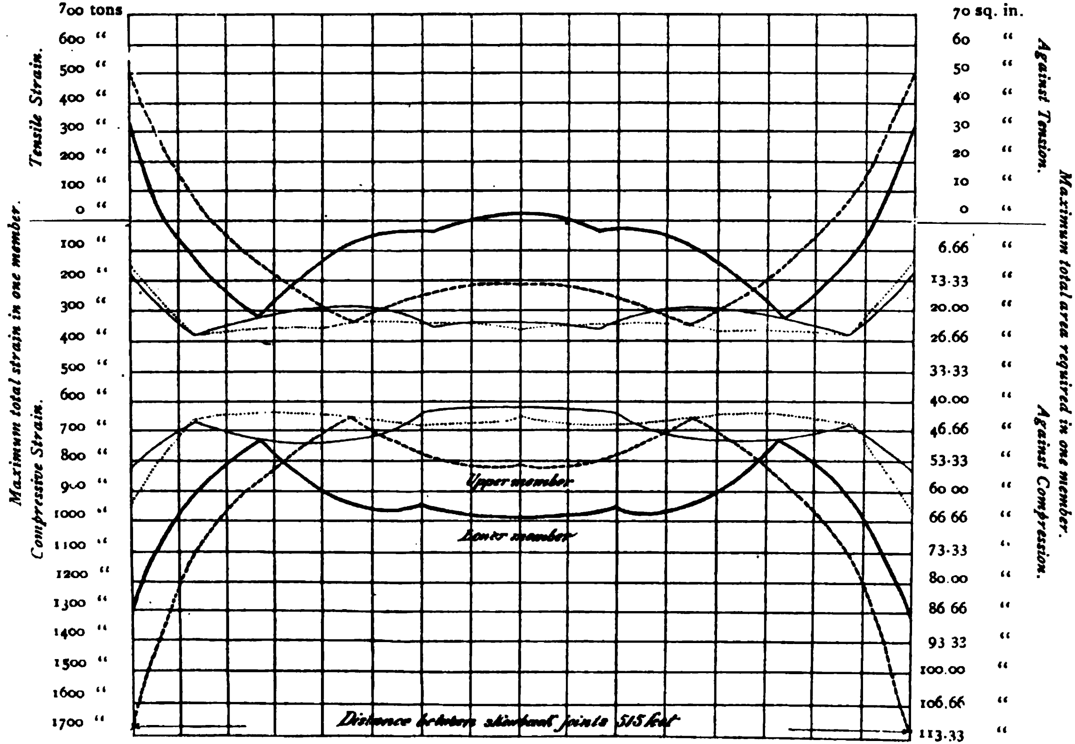
No suspension bridge system, yet devised, possesses anything like the resistance to change of form which this does, owing to its great depth of bracing; while for equal length of span it possesses greater economy. The catenary to span the same opening must be longer than the arch by the diameter of one tower, as it extends from centre to centre of towers, while the arch will spring from the faces of the masonry. This advantage possessed by the arch, will quite compensate for the joints required in its construction, and which are not needed in wire cables.

Where great height of span is desirable, the cost of masonry to hold an ordinary arch may become so great as to forbid availing of its unquestioned economy. In such cases the chord with its compensating lever or disk attachment, at one or both ends of the arch, will relieve the piers of any desired amount of the thrust, just in proportion to the relative lengths of the lever arms, or relative distances from the centre of the disks, at which the pins are located.

It is, however, when we compare this system with other parts of the suspension system, that its great economy over that system is seen. When we leave the great central span, the chief feature of nearly all suspension bridges, and examine the large sections that must be maintained in its cables over the reduced spans between the towers and anchorages, and compute the necessary weight and great cost of the masonry required to resist the tension of the cables, and compare these features with the shorter and more economic spans and light piers which this system admits of in the approaches, we perceive its remarkable economy over the best suspension system yet devised. To the economy and rigidity secured by the system proposed, we must add in its favor also the important elements of safety and

Fig. 25. **Diagram of Strains of Centre Span. Bridge at St. Louis, Mo.**

Area of one member in end pieces (1-12th of span each) 100.5 sq. in.; for centre piece, 67 sq. in. Distance between the centres of upper and lower member of a rib, 12 ft. Modulus of elasticity of cast-steel, 28,000,000 lbs. per sq. in. Extension of cast-steel by 80 deg. Fah., 0.000.527 of its original length.



The light lines show the maximum strain or area without regarding the influence of temperature.

durability, which are secured in a higher degree by using the material of the chief sustaining member of the structure in compression, instead of tension.

There is no limit except a financial one, to the length of span which may be safely constructed by this system, and spans of 1,500 or 2,000 feet will be found to be entirely within a practical or profitable limit of expenditure.

DISCUSSION

ON UPRIGHT ARCHED BRIDGES, FROM TRANSACTIONS OF AMERICAN SOCIETY OF CIVIL ENGINEERS, JANUARY, 1875.

In reviewing the criticisms upon the paper before the Society, the author will first notice such as have a general bearing upon the subject of bridge building, and afterwards those which relate more especially to the merits of the proposed system.

The principle that the "engineering is best which most fully answers its purposes at the least cost," as expressed by Mr. Welch, is fully recognized by the author, and it is upon this axiom he bases his belief that for spans of considerable length, the system under discussion must ultimately supersede every other one now in use. It may, however, be inferred from Mr. Macdonald's remarks that the author is more ready to preach than he was to practice in the St. Louis bridge the excellent axiom of Mr. Welch; therefore he will briefly refer to them, with the prefatory remark, that whenever it is necessary to test the engineering merits of the design of that bridge by the axiom stated, he will be quite willing to abide the issue.

Referring to the accurate workmanship and expensive material in the arches of the St. Louis bridge, Mr. Macdonald says he doubts if the author " will again adopt this design for the purpose of saving a few pounds of metal." The inference from this is that: 1st, the proposed system must also in all cases involve the same accuracy and costly material as the St. Louis bridge; 2d, that accuracy and peculiar material enhanced the cost of that work; and 3d, the design for that structure was adopted simply " for the purpose of saving a few pounds of metal."

The first inference will be shown to be unfounded before closing

this review, and it will be immediately apparent that the second and third are not justified by the facts.

The ribbed arch system, notably illustrated at the time, in the 350 feet arches at Coblentz, was finally adopted as that on which the design should be made, because the entire bridge could be built in conformity to the law, and with the requisite strength and capacity for less money on that system than on any other, of which the author and his assistants had knowledge; and it is scarcely saying too much to assert that this fact was arrived at, through an amount of careful comparative examination of various lengths of spans, and corresponding foundations, for both trusses and arches, and after such a series of laborious investigations and study as were never before bestowed upon any similar work.

Before adopting the design, satisfactory assurances were obtained from practical steel makers, that the requisite material could be supplied in perfection, and at less cost per pound for the finished steel than double that of wrought iron; while the maximum compressive strains it would bear with equal safety (27,500 pounds per square inch), were nearly, or quite three times as great as could be imposed on the iron. The contract price of the steel work delivered at St. Louis, excluding erection, was 15 cents per pound, and the amount of machine and hand work put upon it, after it came from the mills, was less in proportion to the mill prices than that usually put on wrought-iron bridge work. The mill price was 11¼ cents, delivered in Pittsburgh. Allowing ½ cent for transportation to St. Louis, there were left 3¼ cents, or about 28 per cent. on the mill price for finishing. The tubes and couplings involved the most accurate part of the work, while they constituted by far the largest portion. The average weight of a tube section and coupling being about 5,000 pounds, it will be seen that the contractor received about $162.50 for finishing each, or about $170,000 for all the tubes and couplings. Although unforeseen difficulties were met, as is usual in producing new forms in steel and iron, these were all skillfully surmounted by the contractors without extraordinary exertions, and I am quite confident that both the mill work and the finishing could be duplicated at these prices to-day very readily. If the finished steel had but double the strength, and cost double the price of iron, it would be much more economic in either an arch or truss. To show why it is so, at these relative ratios of price and strength, it is only necessary to refer to the simple fact that the arch (or truss) must support itself before it can support anything else. If the curve of the middle arch of St. Louis bridge were reduced to about one-quarter of its present height, and were of wrought-iron, the safe limit of strength in the metal would be already reached, and it could not support any part it carries, even of the superstructure, without exceeding that limit; whereas if it were of steel of double the strength per square inch, and but half the sectional area or

quantity were used, it would have a surplus of one-half of its strength yet left, and could consequently carry with safety a load equal to its own weight.

By increasing the curvature of the iron arch from this low versed (of sine about 11 feet) it would gradually acquire a surplus strength, available for supporting the roadway and live load, as the horizontal forces would be lessened by increasing the depth of the arch. But even with the versed sine of the centre span (47.5 feet), supposing the allowable strain on the iron to be 10,000, and on the steel only 20,000 pounds per square inch, the iron would require double the sectional area of the steel, and 16 per cent. added to that increased area, to equal the available strength of the steel. But as the steel really bears 27,500 pounds instead of 20,000 pounds, it would require that the iron should be doubled, and 64 per cent. of this doubled weight or section added to it, to possess an available supporting value equal to that of the present steel arches. These arches weigh (exclusive of vertical and horizontal bracing), nearly 4,000,000 pounds. If of iron, their weight must have been doubled and had 64 per cent.* of the doubled quantity added to it. In short, they would have weighed about 13,000,000 instead of 4,000,000 pounds, whence it is evident the author did not adopt the design simply "for the purpose of saving a few pounds of metal," but to save several million pounds.

As the contract price of the steel was 15 cents per pound, or about $600,000,—and as the work, if in iron, would have cost at least 10 cents per pound, or about $1,300,000,—it must be apparent that the steel was more economical. The erection of 6,500 tons of metal would also have cost largely more than that of 2,000 tons. Besides this, the horizontal thrust of each arch would have been increased about 2,000 tons, and this would have involved the necessity of a much greater quantity of masonry to resist this horizontal force. It will therefore be seen that there were several good reasons for using the more expensive material.

While the author feels sure he could with his present experience materially lessen the cost of the bridge, if it were to be executed again by him, he is quite certain he could not do so by making any important change in the design, if the ribbed arch were used. No ordinary truss system could be so cheap. The only important improvement he can suggest upon that design, is contained in the paper submitted.

If judged by the rule stated by Mr. Macdonald, the design will be fully vindicated. He says: "In most cases the problem of covering a given space is best solved, and with the greatest economy, when

* The above figures are only designed to be approximately correct. A careful investigation, in which all of the elements involved are included, would doubtless modify the percentages named. They are, however, sufficiently correct to show the enormous difference in weight between the requisite quantities of iron and steel.

the cost of superstructure about equals that of its supports." As originally designed, the substructure (piers and abutments) was estimated at $1,540,080, which was only $79,662 more than the original estimate for the superstructure, or 2½ per cent. on the aggregate of both; while the actual cost of the substructure was for—

Abutments	$1,000,214.35
Piers	1,073,689.91
Tools and machinery	290,548 00
Total,	$2,364,452.26
Superstructure (excluding approaches)	2,234,655.42
Difference	$129,796.84

The original estimates were increased by some alterations in the design, which consisted in sinking the east abutment pier to the bed-rock 60 or 70 feet deeper than was first intended, and in using a large quantity of granite ashler; also in doing much of the work at night and on Sundays, under the delusive hope that the superstructure would be completed in the contract time. The cost of superstructure was chiefly increased by widening the bridge 4 feet, placing an iron wind truss under the upper roadway, and making some other modifications in the design; and also largely by extra payments to induce the contractors to hasten its completion. Still with all these, the difference in cost of sub and superstructure is only about 3 per cent. on their aggregate cost.

This evidence is not advanced because the author has faith in Mr. Macdonald's rule, but because it is testimony which to him may be interesting, if not convincing.

The addition of the general items of engineering and contingent account proportionately charged ($400,000), will make the actual cash cost of the bridge, excluding approaches, as above stated, $4,999,107.68.

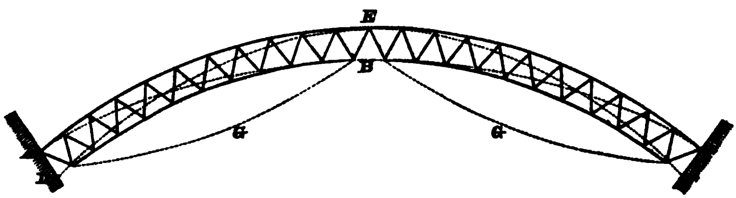
The total outlay as given by the auditor for everything in any manner directly connected with the construction of the work (excluding the tunnel and land damages but) including salaries, rents, engineering, steam and street railways, gas and water-pipes; all of its approaches; losses by failure of contractors; extra compensation and bonuses to expedite the work, etc., etc., amounts to $6,680,331.47.

The additional cost of the bridge aggregating nearly $6,000,000 more, consists almost wholly in items of discount, interest and commissions on bonds; charters, legal expenses and similar expenditures, including $1,086,000 for real estate and right of way. These have, however, no bearing upon a discussion of the merits of the design as an engineering question. In judging of its economic merits, engineers should not lose sight of the fact that a broad and unobstructed street with its sidewalks and roadway for four lines of wheeled vehicles, in addition to two lines of steam railways, is carried over exceptionally long

openings, and upon unusually deep foundations, the maximum moving load being equal to that of three ordinary railway bridges.

Mr. Shreve says: "The paper before the Society appears to be an acknowledgment of the 'disadvantages of the system adopted for the superstructure of the St. Louis bridge.'" This is an error, and misled by it, he falls into several others, in criticising the St. Louis bridge. He says: "Suppose the crown to rise, the lower tube if relieved of compression at the abutments, would not be strained at any point. Bracing beneath a parabolic arch uniformly loaded, can receive no strain and is useless, and if the curve of the tube considered is not a parabola, it is so near it that the strains, which are transferred by the braces to the lower tube, are too small to be noticed. The conclusion is unavoidable that the upper tube at times must bear the whole load, and even more, for the tubes 'are rigidly held to the abutments by anchor bolts,' and a large extra amount of strain is in this manner brought upon the loaded tube." When cold causes the crown of the arch to be depressed, he declares that then "the lower tube must just as surely take the whole load, and the upper one be useless."

Mr. Shreve suggests a modification of the ribbed arch by which this supposed alternate imposition of the entire load upon the upper and lower members can be avoided. As the diagram with which he illustrates this furnishes a very convenient means of demonstrating his errors respecting the St. Louis bridge, it is reproduced with modifications.



This diagram differs from the St. Louis arches in having a section of the lower tube omitted at the centre and at each abutment, and in having the upper tube jointed at the centre and at each abutment.

Increase of temperature will cause the arch to rise. This will shorten the central space in the lower tube. If the omitted central section were in place when the arch begins to rise, it would evidently be compressed; and if the temperature were sufficient, the entire compressive strain would certainly be taken off the central joint in the upper tube, and be transferred to the restored section in the lower one. No compression could come on the lower tube at the abutments if the omitted sections there were restored, as the rising

of the arch would increase those spaces. The whole load would, therefore, be still sustained at the abutments by the upper tube, but *by the lower one at the centre.* Mr. Shreve thus falls into another error in supposing that "the lower tube if relieved of compression at the abutments, would not be strained at any point."

If the omitted sections at the abutments were restored and the arch were depressed by cold, the compression, which in the preceding case, existed in the lower tube at the centre, would be transferred (in proportion as the depression increased) to the central joint in the upper tube; while the compression in the upper tube at the abutments would be taken off, and be transferred to the lower one at these points. Mr. Shreve is, therefore, a third time in error in supposing that when the crown of the arch falls "the lower tube must just as surely take the whole load and the upper one be useless," because the whole load is then sustained at the centre of the arch *by the upper tube.*

The centres of pressure in these two opposite cases would alternately follow the dotted lines *A B C*, and *D E F*. Greater extremes of temperature would throw these lines at the centre, above and below (or outside of) the arch, and *tension* would thus be created in the middle of that tube which would be in compression at the abutments.* Where these lines of pressure intersect each other in the haunches of the arch, the load must always be borne in nearly equal portions by each tube. In these parts of the arch it can never be imposed upon one tube alone. Hence Mr. Shreve falls into a fourth error when he declares that "each tube must contain a quantity of material sufficient to resist the strains caused by a full load."

Extremes of temperature are thus shown to cause in the tubes great alternations of pressure only in the crown and near the abutments; and these extra pressures can only exist at the same time in the crown of one tube and the abutments of the other, and *vice versa.* They result from temperature in the metallic ribbed arch, whether its curve be parabolic, circular or elliptic, and whether uniformly loaded or unloaded; and they can only be transferred from the ends of one tube to the crown of the other *by the bracing.* Hence Mr. Shreve makes a fifth mistake when he asserts that "bracing beneath a parabolic arch uniformly loaded, can receive no strain and is useless."

There is no difficulty in determining the location of the centre of pressure in any part of the ribbed arch under the different conditions of load and temperature, when the moduli of elasticity and of expansion by heat are known; and hence there need be no uncertainty in proportioning each tube to bear its part of the maximum pressure,

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* This tension can never occur in the St. Louis bridge, owing to the initial stress caused by the weight of the superstructure.

even if its ends be bolted to the abutments. Mr. Shreve, however, thinks there must be, and declares as an axiom "that a plan in which such ambiguity of strains obtains is sufficiently defective to be rejected without further examination." His plan of investigation, seems, however, to have escaped the crucial test of his axiom, for its results are not without considerable "ambiguity," inasmuch as they lead him to commit a sixth error in declaring that "the strains which are transferred by the braces to the lower tube are too small to be noticed," when in reality, with a full load and maximum temperature, these strains will equal about 5,000 tons in any one of the arches he has criticised.

Mr. Shreve makes a seventh mistake, in assuming that 25 per cent. should be added to the material of the tubes over what would be required if the same material were used in tension. The ratio of length to diameter in compression members is too important an element to be thus lightly considered. The character of the material must also be taken into account. A prudent engineer would not trust cast-iron in tension with half the strain he would allow in compression, provided the material were in the form of a tube 6 or 8 diameters in length. The cast-steel in the tubes of the St. Louis bridge will bear safely much more in compression in its present form than it could possibly do in tension. Hence the extra 25 per cent. assumed by Mr. Shreve is wholly erroneous.

The dotted lines, G, G, placed below the lower segments in the diagram, by which the curves of these segments are reversed, will at once show that greater resistance under partial loading will result if the depth of bracing be increased by thus reversing the curvature of these members. Thus modified they will closely resemble the counter-arches suggested by the author, and exact calculation will demonstrate that in proportion as they approximate them in form, the economy of the structure will be increased. Referring to the jointed halves of his diagram, Mr. Shreve says, "that the greatest tension in the lower arc of either segment is when that segment alone is fully loaded, is self-evident." This constitutes Mr. Shreve's eighth mistake. Exact calculations show that this is neither true of the rigid arch, like those at St. Louis, nor in one with three joints, like Mr. Shreve's illustration. In both cases greater tension will occur in the lower members when the maximum load per foot has advanced so as to cover either three or five-eighths of the entire span. This fact is shown graphically in Fig. 14, accompanying the paper.

Mr. Shreve attempts to demonstrate that 57 per cent. of the material used in the St. Louis arches would have accomplished equal results with ordinary horizontal trusses; whereas it is really beyond the power of any one to show that thrice 57 per cent. of it, could

accomplish any such thing.* He closes his criticism of the St. Louis bridge with the remark that "engineers are likely to be satisfied, for the present generation at least, with what has already been done in the construction of steel arches." This corollary is certainly sustained by his method of expounding the principles involved in them.

Maj. Pope makes an admirable presentation of the apparent theoretical and practical advantages of the suspended arch over the upright one. But in doing this, he makes out a stronger case against the horizontal truss system, which he advocates, than against the one under discussion, as we shall presently see. In his comparison, between the two systems of arch construction, it must be manifest that every objection urged against the arch applies equally to the bow-string girder, which is simply an arch provided with a chord instead of abutments, with which to resist the horizontal forces. Whether these forces be resisted by the chord or by the abutments, the necessity of maintaining the integrity of the plane of the arch is equally and absolutely imperative. If we reverse the arch in the bow-string girder, we reverse the strains, and have to all effects and purposes, a suspended arch, as much so as if back chains and anchorages were substituted for the compressive chord. In one case the centre of gravity is above the points of support, and in the other below. As it is necessary to brace all bridges against lateral forces, so as to make them practically immovable, no more bracing can be needed for the bow-string girder whether the centre of gravity be vertically above the points of support or vertically below them. The element of gravity cannot come into play to increase the strains on the bracing in the one case, nor to decrease them in the other, so long as the plane of the arch remains vertical and the centre of gravity is in that plane. If we are dealing with structures that are to be permitted to sway from side to side, the case will be quite different. In such event the suspended arch, and trusses of the Fink type, may do with less lateral bracing than the upright arch or upright truss, but not otherwise. This fact must be evident on reflection. It is only when the bridge is permitted to sway to the one side or the other that the gravity of

* I will state for the benefit of those who desire to investigate this subject, that one arched rib of the centre span at St. Louis (exclusive of lateral bracing) weighs 490,342 pounds. Of this, 328,286 pounds are in the tubes (including bands and couplings). The tubes are all of cast-steel, tested to 55,000 pounds per square inch without permanent set, and the highest maximum strain they must bear will not exceed 27,500 pounds. The remainder of the rib is of wrought-iron, the allowable strains on which is 10,000 pounds per square inch. Four of these ribs constitute the span. The total dead load of the span is 8,000 pounds, and maximum live load 6,400 pounds per linear foot. The clear span is 520 feet, and the versed sine 47.5 feet. The upper roadway is an unobstructed street, 54 feet in extreme width, with double line of railway below. Allowable tensile strains in wrought-iron carrying the railways, 5,000; in other wrought-iron, 10,000, and in steel, 20,000 pounds per square inch. Any other data that may be desired will be cheerfully given.

the structure can be made available to lessen the strains on the lateral bracing. Whenever we assume that no swaying shall occur, we must assume that the element of gravity cannot enter into the calculations which determine the strength of the lateral bracing.

It being a fundamental condition that oscillations shall be reduced practically to zero in first-class bridges, the advantages of gravity claimed by Maj. Pope for the suspension bridge falls likewise to zero. It is only during erection that the effects of gravity involve greater care, and in all cases, probably somewhat greater expense, in the upright arch or truss, than in the suspension bridge. But it is questionable whether we can safely trust lighter lateral bracing even in a structure that is permitted to oscillate; for the momentum incident to the vibration may cause the destruction of the bracing before the opposing element of gravity is brought sufficiently into play to save it.

The bow-string girder being simply an arch, with a chord instead of abutments, it is evident that to insure equal perfection, security and stability for its compressive member, there must be precisely as accurate workmanship, equal care in proportioning the length and diameter of its individual parts, and the same amount of lateral bracing as though its horizontal forces were resisted by abutments. The question then naturally suggests itself, if these are fatal objections in a bow-string girder, wherein does the horizontal upright truss differ from it so much, that its compressive member can have less accurate workmanship, less regard for the relation of length to diameter in fixing the sizes of its various parts, and less lateral bracing to retain it in its upright position.

Maj. Pope says: "Each rib is by itself utterly helpless, even to carry its own weight, and must, therefore, be connected with other ribs by an elaborate and expensive system of lateral bracing. Its construction must be tubular, or rectangular, or of some similar form suitable to resist flexure, and all such forms are expensive. It abounds in joints, each one of which must be carefully and perfectly fitted. The lateral bracing must be so complete as to thoroughly secure the various ribs at intervals of not greater than ten or twelve diameters. To erect it in place is a difficult and dangerous task. The centre of gravity is high relatively to its base, and, consequently, the forces of nature act against rather than with it." The author is unable to discover in this attempt to point out the disadvantages of the upright arch, a single item which does not as well apply against the system Maj. Pope is defending.

Engineers do not need to learn that in resisting equal compressive strains in any truss system, it is necessary to observe the same laws in proportioning the sizes of the members and their sectional forms, and that there is the same need of accuracy in adjusting their bearing surfaces, as if they were to be used in an arch. In every hori-

zontal system of trussing, where the points of support are beneath the centre of gravity, it is just as imperative that the vertical plane in which the rib stands, shall be preserved, as if the rib were an arch, and that it is as helpless until braced to its mate. To retain the arched rib, or the horizontal one in place, the resistance to lateral motion must be found at the points of support below the centre of gravity, and Messrs. Pope and Clarke, who question the economy of the lateral bracing required in the proposed system, surely will not challenge these propositions:

1st. With a given base, the greater the *height* at which the compression member of a truss is held, the greater will be the bracing required;

2d. The greater is the *length* of the member held at a given height, the greater will be the bracing required; and

3d. The greater is the *weight* of the member held at a given height, the greater will be the bracing required;—in each, all other conditions being equal.

Now, it is incumbent on those who assume that the upright arch system proposed cannot be so cheaply braced laterally, to show what conditions exist in the truss system which overbalance the advantages the arch possesses by virtue of these axioms:

1st. The truss must have equal weight with the arch for economy.

2d. The *length* of the member held at the greatest height in the truss is much more than in the arch.

3d. The *weight* of the portion of the member held at the greatest height in the truss is much greater than in the arch, for three reasons—first, that portion is much longer; second, the section of the truss is greatest in the middle, while that of the arch is least in that part; third, the weight of the truss being greater than the arch with its chord in the proposed system, the compression member of the truss must bear the weight of a heavier chord, and hence must have greater section at its centre on that account. That the wind bracing of the truss is really more expensive must, therefore, be evident.

When the fact is recognized that, in metal arches, the lengths of the individual members composing the arch should be straight, and not curved from joint to joint, these members can be of any form of section used in any of the truss systems, and they may be of cast or wrought-iron, riveted plate, angle or channel bar, or of any form of iron or steel suitable in any truss of equal dimensions, the objections urged by Messrs. Macdonald, Pope, Clarke and Nickerson will apply with equal force against every truss system in existence. Whether the members are butted against each other at the joints, secured by couplings, riveted together or held by any other proper method, there is no more excuse for permitting inaccurate workmanship in the truss than in the arch, nor can it possibly be shown that there is less dan-

ger from inaccurate joints in the truss than in the arch. In the ribbed arches at St. Louis the case was unusual, because two long lines of tubes were extended from skew-back to skew-back, parallel to each other, only 12 feet from centre to centre, to form a rib, and the individual members were only about 12 feet each in length. It will be apparent that if a straight truss, 520 feet long and 12 feet deep, were required, that equal accuracy would be needed in each piece, and that if the truss were four times the depth, and each piece two or three times as long, less accuracy would be required. Still nothing more accurate than $\frac{1}{100}$ inch was demanded in fixing the lengths of the members, and this is but little more than the $\frac{1}{64}$ inch admitted by Mr. Nickerson to be easily attainable. The ribbed arch, owing to its shallow depth of trussing, does involve more accuracy than deep horizontal systems; but the system proposed is not the ribbed arch. In all bridge factories, tools are provided by which the ends of compression members are cut to any required angle, with accuracy and facility, so that the different members in the arch, each being, as it should be, straight, the manufacture per pound for the one kind of structure should be no more costly than the other. The difference per pound, on the system proposed, will be unobjectionable.

In all truss bridges where the points of support are below the centre of gravity, the lateral strains in the top members are transmitted either wholly through the end struts by virtue of their stiffness, to the points of support at the ends of the truss, or else partly by these struts and partly by the intermediate ones, down to the floor system, and thence by that system to the ends of the truss. This being the fact, and it being true that the compression members of the arch at the ends can be straight and stiff, just as well as the end struts of the truss, and that they incline at an angle by which the distance to the floor-beams is much less than in the end struts of the truss, and therefore more easily braced from the floor system, and that two-thirds or two-fourths of the length of the arch is much nearer the floor system than is the compression member of the truss; the author is at a loss to comprehend how any engineer, who fully understands the system of lateral bracing in the drawings, or the facility which the greater proximity of the arch to the floor system gives for any other reliable and economic arrangement of lateral bracing, can question the ease and cheapness with which this bracing can be provided.

Maj. Pope and Mr. Clarke both evidently misapprehend this matter, which is partly owing probably to an inaccuracy in one of the drawings. The sectional views of the bridges, however, show that there is no necessity for the roadways being obstructed by the bracing. Maj. Pope is mistaken in supposing that the chords are simply suspended from the arches. They are secured to the arches—in addition to the suspension rods—by vertical struts at the centre of the arch and midway between the centre and the ends of the arch, as will be seen on

the drawings. Between these points their weight and that of the roadway should prevent them from rising, as they are perfectly straight, and are held from descending at the intermediate points by the suspension rods. Introducing more struts would not add to the cost, as they act as suspenders. The floor system, however, being thoroughly held vertically, and strongly braced laterally, as is shown by the drawings and tables, would not be quite "as limber as a whip-lash." The compressive strains to be borne by the chords are as safely provided for as in the top members of any railway trusses that are built. In both designs the lateral floor bracing is very thorough and ample.

Mr. Clark assumes that a platform merely suspended from an arch, must sway from side to side under a passing load. He says: "Horizontal bracing alone will not prevent lateral motion, for the lower chord being in tension will vibrate like a stretched string." These views seem strange to the author, inasmuch as they are advanced in defending a system of bridge-building in which on every through bridge, the platform carrying the railway is also suspended from its compression member, and has its chords in tension. Mr. Clarke says: "It is neceseary to connect the floor by rigid angle bracing with the upper chord, which being in compression never leaves a straight line." The author is at a loss to understand by what law it is assumed that in tension a long member is more likely to leave a straight line, than when in compression. It would follow by this reasoning, that if each were released from its lateral system of bracing, the member in compression would be the last to leave the straight line, whereas the converse is true. Mr. Clark has here evidently failed to make himself clearly understood. The fact is, the floor system in the through truss bridge has its chords in tension, while in the Fink truss it has its chords in compression, and the wind truss of the St. Louis bridge, under the upper roadway, has its chords in neither tension nor compression. This shows that in either condition the chords are available for bracing. Certainly, the simplest way to secure a platform against lateral movement, is to extend a system of lateral bracing in a horizontal plane, directly between the two opposite points of support, and at these points to secure the system to the chief supporting members of the structure, and thus make its gravity an element of stability for the intermediate roadway. Mr. Clarke's argument would lead one to suppose that it were better to throw up four posts 18 or 20 feet above this platform, and then, having these strongly braced against lateral motion, extend a horizontal system of bracing between them, and from this stilted system at intermediate points, send down struts to the platform below and thus avoid the simple and direct horizontal bracing between the points of support: or else assist the latter to do what it could much more economically do without the help of its lofty coadjutor. Mr. Clarke adds: "If this were done in

the bridge proposed by the writer, (that is 'connect the floor by rigid angle bracing with the upper chords,') some of the economy of material claimed for it would disappear." This is certainly very true, but to the author it would seem as unnecessary as to hold the ground floor of a rope-walk by means of rigid angle bracing with the roof above it. The structure which is raised above the roadway, whether it be a truss or an arch, is put there solely to secure the roadway against vertical movement. Lateral bracing is absolutely necessary to preserve its position against the effect of wind and vibration. When this is provided, every additional lateral strain that is thrown upon it by the roadway beneath, must involve the use of more material to transmit that strain up to the top chord, and through it to the end posts, and then down again through them to the points of support, than would be required if that strain were transmitted to those points in a direct horizontal plane. This must be so evident to the distinguished engineers (Messrs. Pope and Clarke), who have discussed the question of the lateral stability of the proposed system, that further argument is unnecessary.

As nothing can be more evident than that the horizontal plane between the points of support is the most economic location for lateral bracing, it follows that by rigid connections from bracing located in this plane with the structure above it, any lateral forces affecting the stability of the members above can be more economically brought down to this system, and transmitted through it to the points of support, than is possible by reversing this order of bracing. It follows, too, that the less distant the upper member is from the lower system of bracing, the more directly and economically can the strain be brought down to it.

The author claims that the economy and facility with which lateral support can be imparted to the arch through the wind bracing of the roadway are advantages possessed by this system over that of the horizontal truss systems. Maj. Pope says, however, that where the lateral floor bracing is weakest in this system is just where it needs the greatest strength, if it be required to support the ends of the arches where the bracing between them is intermitted on account of head room for the locomotive. Is not he forgetting the difference between the chords and the system of vertical arch bracing proposed and that of the ordinary truss systems? The horizontal forces of the arch are all, by its peculiar bracing, thrown directly on to the chords at the ends; consequently these strains require the chords to be of uniform section throughout, and for this reason they are not like ordinary truss chords, weaker at the ends of the truss, whilst the lateral bracing between the chords in this, like any other truss, is not the weakest at the ends, but the strongest there.

Mr. Whipple's theoretical comparison of the economy of the lever-disks and chord arrangement suggested, seems to the author not ex-

actly fair, inasmuch as he bases his conclusions on the fact that the chord of a bow-string girder braced between chord and arch by uprights and diagonals resist but 39 per cent. of the strain upon the whole material of the truss. From this basis he proceeds to estimate the saving by the chord system proposed, which is incorrect, for the reason that the arch proposed is braced in a much more economic manner against unequal loads than in the ordinary bow-string girder, and this enables the chord to be lighter, which in turn diminishes the weight of the arch. Again, the chord in the proposed system resists *all* of the horizontal forces of the arch, and therefore it constitutes much more than 39 per cent. of the resisting material, if the lever-disk system is not used. But if it be used, the chord will receive but one-half of the entire thrust of the arch, and thus when it saves half of the weight of the chord, there is an additional saving in the arch itself by being relieved of this much dead weight. It is evident, then, that in such a comparison the system should first receive credit for a reduction in the weight of the arch itself, due to a more economic bracing against unequal loading, and, second, for the additional saving of material in the arch resulting from being relieved of half the weight of the chord, both of which seem to have been overlooked by Mr. Whipple.

In this connection the author will state, that detail plans for a bow-string girder on the system proposed, 517 feet between the end pins of the chord and with one-eighth versed sine, were carefully prepared under the direction of Colonel Flad, to determine a wager that this truss would weigh less than *two-thirds* of the weight of a horizontal truss to carry the same load (2,500 pounds per linear foot) over the same length of span, using the same kind of material and with equal safety; and to be one of a design used in several of the longest span bridges in this country. The weights, strains, etc., of the horizontal truss were to have been supplied twelve or fifteen months ago, to determine this wager, but this has not yet been done. This bow-string girder, including everything, weighs 3,100 pounds per linear foot; the arch is of steel, to bear 20,000 pounds per square inch; all the other parts are of wrought-iron, including the chords, which take the entire thrust of the arch.

It will certainly be interesting to the profession to know whether the author would win or lose this wager, under the decision of a designated umpire who stands in the front rank of bridge engineers, and by whom all questions of safety, details of calculations, and proper proportions of members are to be examined and revised, and the question of total weight decided, in the event of the decision of Col. Flad being challenged. Perhaps the simplest way of determining the question of economy in the proposed system of bracing the arch under partial loads, will be for those who deny its existence to submit to the Society the details and weights of a horizontal truss

of 517 feet span on the above data, and show how nearly it approximates to 3,100 pounds per linear foot in weight.

Engineers who object to this system on the ground that "great increase in lengths of span generally seems unnecessary," lose sight of the fact that if there can be great economy obtained in long spans by this system, the cheapening of shorter ones by it must be admitted.

With reference to steel in bridges, it would seem that where its advantages are so plainly manifest as they have been shown to be in reviewing Mr. Macdonald's remarks, it is the duty of all engineers to encourage its use in the construction of bridges, roofs, etc., in preference to iron. The author is confident that if such were given, it would not be long before a quality would be supplied at moderate prices which could be easily worked, and be reliable in tension as well as compression for strains three times as great as the wrought-iron usually put into bridges. Steel may be considered as iron more highly refined; hence it would seem that in a structure where weight is such an important element of cost, every encouragement should be given to produce the most superior material. If this were done, the demand would soon induce a competition that would reduce the present cost.

Mr. Clarke makes an objection to the bow-string girder because "practice has shown that the deflections on a bow-string girder are very great at each end, owing to the want of height of the truss at these points." This fact the author is inclined to believe is by no means well established. It may result from defective designs, and may be partly imaginary. The proposed system, however, enables the fault affirmed by Mr. Clarke to be economically overcome in a manner not possible with the ordinary bow-string. In it, owing to the loss of economy in long compression members, the height of the truss is kept down in spans of important lengths, but in the system under discussion a versed sine of one-sixth or one-seventh wili be found to be among the most economic proportions for ordinary lengths that can be given, which will greatly increase the depth at the ends. If this deflection exists in ordinary bow-string trusses to the extent claimed, it results more from the manner of trussing with verticals and diagonals between the arch and chord, than from want of depth. The method proposed distributes in a manner quite different the strains from unequal loading through the action of the inverted arches, and prevents the objectionable deflection.

DISCUSSION

OF UPRIGHT ARCHED BRIDGES. FROM TRANSACTIONS OF AMERICAN SOCIETY OF CIVIL ENGINEERS, JUNE, 1875.

Mr. Shreve (page 162) makes additional criticisms on the St. Louis Bridge, which I reluctantly notice.

After showing so many fallacies in his first attempt to explain the principles of the ribbed arch, I did not suppose that I should be compelled to point out additional ones by the same writer.

As Mr. Shreve now makes a deliberate assertion calculated to arouse public anxiety respecting the St. Louis Bridge, and one apparently sustained by mathematical deductions, based solely, as he assures his readers, upon premises furnished by me, and as he is known as the author of a work on bridge strains, and may therefore be considered an authority, the necessity of showing the absurdity of his "new analysis" becomes imperative.

After having first proved to his own satisfaction that the tubes composing the central arch of that bridge contain 47 per cent. *more* metal than would have been necessary had a proper system of construction been adopted, he now attempts to prove that they have actually 52 per cent. *less* than they ought to have.

Alluding to his first mistakes, he introduces his present investigation with the following preface:

"I propose to admit these errors, and to make a new analysis and a numerical calculation of the strains upon the ribs of one of the arches of the center span, assuming nothing, but basing my whole argument upon premises furnished by Capt. Eads' own statements contained in his papers which have appeared before the Society."

In the next breath, after this solemn assurance that his whole argument is *based upon my statements*, he declares that the sectional area of the tubes at the center of the span is only 60.84 inches. As this area is really over 75 inches, I am thus made responsible for a gross error at the very threshold of his investigation, while his readers are at the same time led by his assurances to place implicit faith in his erroneous data. Mr. Shreve's argument is not, therefore, based upon statements furnished by me. The sectional area of the tubes is certainly the most important element in his argument, and

he starts with an error in this, which, if corrected, would reduce, by 16,000 pounds per square inch, the 57,143 pounds which he assures us, with such precision, must be borne by the steel. If this error be corrected, the greatest strain, Mr. Shreve discovers, even by his defective analysis, would be about 41,000 pounds per square inch, or 14,000 pounds *less* than was put upon the steel when it was tested; namely, 55,000 pounds. The immediate strengthening of the bridge recommended by him may, therefore, be safely delayed, at least for the present.

Mr. Shreve says: "Each tube has an envelope of wrought-iron ¼ inch thick." This is an assumption for which he has no basis in any of my statements. The envelope of each tube is of *cast-steel*, and it forms an integral part of the tube, and bears with the tube staves its full share of the compression in the arches.

The sectional area requisite to resist the computed maximum strain in the lower tube at the center was found by careful investigation to be 67 square inches; the allowable pressure being 30,000 pounds per square inch. After the computations were made, the sectional areas of all the tubes were slightly increased on the detail drawings, to guard against possible inaccuracies in workmanship. The central section was increased from 67 to over 75 inches.

Mr. Shreve undertakes to prove that the maximum strain on the central part of the lower tube, *with maximum temperature* and load, greatly exceeds what I have asserted to be the greatest pressure that can be imposed on the steel; namely, 27,500 pounds per square inch.

I propose to explain in a general manner the problem he has undertaken, and then point out the defective method by which he arrives at his results.

I will first refer to the fact that Mr. Shreve persists in construing my paper on "Upright Arched Bridges" as an essay on the St. Louis Bridge, and has therefore taken my general explanation of the effects of temperature upon its arches as exact data on which to base a technical analysis of the strains of that structure. My paper was not, as he supposes, intended as an acknowledgment of the disadvantages of the system adopted by me for that bridge. It parades no praise of the bridge before the Society, nor is it my wish that that structure should be spared the most thorough criticism. The bridge was referred to very briefly for the sole purpose of pointing out disadvantages inherent in the best system of metallic arch construction (as I think) known at the time I selected it for that structure, and to illustrate more clearly how these disadvantages could be avoided by a new system, which it was the special purpose of the paper to present to the Society.*

* This system was the legitimate subject of criticism before the Society, and to it Mr. Shreve has failed to address his remarks, having misconstrued the purpose of the paper.

These disadvantages are almost wholly the result of temperature. I endeavored to explain them in a popular manner, so as to be easily comprehended by gentlemen who, like Mr. Shreve, have never made the ribbed arch a study. I purposely avoided complicating my explanation of thermal effects on its arches, and hence omitted in it any reference to the modifying influence of the elasticity of the steel, the rate of its expansion by heat, the effects of the full and of unequal loads, the dead weight of the structure, and the strains incident to the bolting of the ends of the arches to the abutments; all of which are absolutely essential elements in determining the maximum strains in its arches.

It did not occur to me that any one would attempt to base an elaborate scientific investigation of the strains in a ribbed arch upon such general remarks about the influence of temperature upon it, and this, too, without regard to the other equally essential data of the problem. Knowing, however, that my explanations were of a general character, and supposing that some of my readers might desire *accurate* data as to the precise extent of these effects, after these various modifying influences had been taken into account, I accompanied my paper with a diagram of the strains of the bridge, showing what they would be without the influence of heat, and what they *really* were, under its influence; and at the close of this general explanation, I called attention to this diagram, where the extent of these effects is *accurately* shown.

In 1868 I published, in an appendix to my report on the St. Louis bridge, the scientific methods by which every strain in the present structure has been investigated. The depth of the rib was afterwards altered from 8 to 12 feet, and the versed sines of the arches were also altered, but this appendix contains the methods and an explanation of the principles upon which all the investigations of the completed structure were based. The diagram before referred to gives a graphic representation of the strains of the central arch, as thus determined; also the sectional areas of the central and abutment tubes, the modulus of elasticity, and the rate of extension of the steel by temperature. These, with the additional data given subsequently, furnish all the facts requisite to investigate the strains of the St. Louis bridge. By applying the scientific processes, explained in the appendix to my report of 1868, to these data, any one competent to analyze the strains of the bridge can ascertain its strength.

The scientific investigation published with my report of 1868, Mr. Shreve thinks, is to the majority of engineers "incomprehensible," and "unsatisfactory," although it was carefully revised and simplified by Chancellor Chauvenet, one of the most accomplished mathematicians this country has produced. That it is unsatisfactory to Mr. Shreve is both evident and unfortunate, for he discards its use

altogether, and casts aside even the necessary data stated on Fig. 25, and investigates the subject in a manner peculiar to himself.

The problem Mr. Shreve attempts is to determine accurately the strains in one of the four ribs of the central arch of the bridge *when under the influence of the greatest temperature and load.* His diagram will serve to illustrate the rib, which is formed of one upper and one lower cast-steel tube, 12 feet apart, extending from abutment to abutment, and each being strongly secured to the other by a triangular system of bracing between them.

The medium temperature of 60 deg. Fah. was assumed in designing the rib. At 140 deg. it is nearly 7 inches longer than it is at 20 deg. below zero, the rate of extension by heat being 0.000,527 of its length for 80 deg. The modulus of elasticity of the steel is 28,000,000 pounds per square inch. Owing to the elastic nature of the steel, the dead weight of the structure, at medium temperature, causes each tube to be shortened about 2½ inches; that is, the rib, if laid sidewise upon the ground, would be 2½ inches longer than it is in its present upright position with the bridge unloaded. In proportion as the bridge is loaded, the tubes become still more shortened. The shortening of both tubes as the load is increased is almost exactly the same, so long as the temperature remains at 60 deg. At this temperature each tube bears almost exactly one-half of the compression in the rib when the bridge is unloaded, or when fully loaded. If the temperature be raised or lowered the case is quite different. If the tubes are lengthened by heat, the arch rises at the centre, as the abutments are practically immovable. As the arch rises, the compression in the upper tube at the centre is lessened by the altered curvature of the arch, and the compression in the lower one at the centre is proportionately increased. *

We see then that *heat* produces in steel an effect exactly opposite to that of *pressure.* The one extends its length, and the other shortens it. If we take under discussion one of the steel tube sections of the rib (which are each about twelve feet long, and perfectly straight), and erect it as a vertical column, we can, when it is extended by any given temperature, load it sufficiently to reduce its length and make it correspond with that which it would be if unloaded at a lower temperature. If the temperature be 140 deg., we may reduce its length, by pressure, to what it would be when unloaded at 60 deg. or at 20 deg. below zero.

The tube sections composing each entire tube of the rib are affected by heat and pressure precisely in this way: let us suppose, for instance, that the *unloaded* rib is expanded by heat until the entire horizontal force in the center of the rib is borne by the lower tube, then the moment we begin to load the bridge the resistance of the

* Near the abutments, at the ends of the tubes, these strains would be reversed.

upper tube is brought at once into play, for the increased strain must shorten the lower tube and allow part of the pressure to be borne by the upper one. Just as we continue to add on weight uniformly over the bridge, will we lessen the difference between the strains which existed in the two tubes when we began to load the structure, until finally, after exceeding the maximum load it was designed to bear, we can produce, by pressure, a shortening of both tubes to such degree that each will bear exactly half of the whole horizontal force in the arch; and then we will find each tube exactly the length it is at 60 deg. of temperature with the bridge *unloaded*, although the temperature at the time may be 140 deg.*

It must, therefore, with this general explanation, be evident, even to a tyro, that when we undertake to investigate the strains in the St. Louis arch, *except when its temperature is at 60 deg. Fah.*, it is *absolutely necessary* that we bring into our computation both the rate at which the steel is extended by heat, and the modulus of its elasticity, or the rate at which the steel is shortened by pressure. Without these two elements of the problem, it is simply impossible to determine what portion of the total strain is borne by each tube.

It is, therefore, absurd to challenge the correctness of the results of an investigation in which both of these elements have been carefully considered, because they do not agree with those of a calculation in which they have been both absolutely ignored. As they are totally disregarded in Mr. Shreve's "new analysis," although dealing with a temperature of 140 deg., it follows that his alarming declaration that "the great importance of immediately strengthening the ribs of the St. Louis Bridge can no longer be ignored," is based on an investigation so palpably defective, that its results have no value whatever, except to "point a moral."

The diagram before referred to shows as the result of careful investigation that the strains on both tubes are considerably less in the haunches of the arches than at the crown and abutments. Mr. Shreve tries to maintain his error on this point, by showing that the sectional areas of the tubes, *as constructed*, with the exception of the first five sections nearest the abutments, are in reality uniform throughout the arch. This will not avail Mr. Shreve, as he was discussing the ribbed arch from a scientific standpoint, while these areas were made uniform not because the strains are not less in the

* Mr. Shreve assumes in his calculations that the upper tube must remain without pressure when once relieved of it by expansion, no matter what strain be imposed on the other, for he finds 57,143 pounds per square inch on the lower one, and yet makes no allowance for the shortening that would result from a pressure more than twice as great as the maximum of 27,500 pounds on that tube, even if it really existed. In reality, the maximum pressure results from *unequal* loading, and is not nearly attained under the conditions he has assumed, as the upper tube under these conditions bears a strain of 510 tons at the center of the arch.

haunches, as I stated, but to reduce the cost of rolling the steel by lessening the variety of its sizes, and also to avoid cutting the grooves for the couplings, in tube-staves of less thickness than $\frac{1}{16}$ inches.

Mr. Shreve calls my attention to an inadvertence, or error, which I hasten to correct, respecting the *tension* in the lower member of the loaded half of the jointed arch shown by his diagram. He says, "That the greatest tension in the lower arc of either segment is when that segment alone is fully loaded, is evident." This I declared was an error, and so it is; because the greatest tension in the lower member is when three-eighths of that arc is lôaded. I erroneously stated, however, that the greatest *tension* would occur in this lower member when the maximum load per foot covers either three-eighths or five-eighths of the span. If I had used the word *strain* instead of tension, this correction would have been unnecessary. When the load covers five-eighths, the *tension* will be less in the lower member of the loaded half than with that half fully loaded, but the *compression* in the lower member of the unloaded half will be greater than with the half load.

Mr. Shreve makes the following defense of one of the most important errors in his first criticism:

"Again Capt. Eads writes: 'Hence Mr. Shreve makes a fifth mistake when he asserts that bracing "beneath a parabolic arch uniformly loaded, can receive no strain and is useless.'" For this error, I think I am pardonable when I offer as an excuse, that Rankine, Stoney, Weisbach and every other author I have read, who treats the subject, has made the same mistake. It is, too, an error one is likely to commit, since the most simple method of determining strains, the method of sections and the graphic method lead one so easily into it. Capt. Eads himself has not escaped it: in speaking of the upright and the inverted arch, his words are: 'If either form have an equally distributed load placed on it, no bracing will be requisite to preserve its normal curvature.' In other places in the same paper he gives evidence of falling into the same mistake which he attributes to me."

Mr. Shreve does not in the above clearly state his fifth error. His words are as follows:

"Suppose the crown to rise, the lower tube if relieved of compression at the abutments, would not be strained at any point. Bracing beneath a parabolic arch uniformly loaded can receive no strain and is useless, and if the curve of the tube considered is not a parabole, it is so near it, that the strains which are transferred by the braces to the lower tube are too small to be noticed."

It is evident that Mr. Shreve meant that the bracing between the upper and lower tubes of the *ribbed arch* at St. Louis *is useless when the arch is raised by temperature*, and that the strains which are transferred by the braces to the lower tube in that bridge are too small to be noticed. Plainly committed to this record, Mr. Shreve strives to make "Rankine, Stoney, Weisbach and every other author" he has read, and myself also, responsible for a mistake which he now sees so plainly that he actually bases his new analysis on the very fact, that bracing beneath a parabolic ribbed arch uniformly loaded, *is absolutely necessary*. While referring to these authors, he forgets that it would be simply impossible to transfer the enormous pressure he finds in the lower tube at the centre, to the upper one of the abutments, *except through the bracing* which he would make us believe Rankine, Stoney and Weisbach support him in declaring to be *useless*. In discussing his fifth error, Mr. Shreve does not, therefore, seem consistent. If he will read these authors more carefully, he will find they may properly say, that bracing beneath a parabolic arch equally loaded will be under no strain if the arch be composed of one single member *and is not affected by temperature;* but when that member is divided into two parts, one placed at some distance above the other, and the two are strongly braced together, and thus constitute a *ribbed arch*, the case is very different at all temperatures, except that at which the upper and lower members bear equal parts of the load. He will find none of the distinguished authors he names advancing a proposition so untenable as that the bracing in a parabolic *ribbed arch* uniformly loaded, can receive no strain when the arch is affected by extremes of temperature.

IMPROVEMENT OF THE

MOUTH OF THE MISSISSIPPI RIVER.

LETTER

TO HON. CARL SCHURZ, UNITED STATES SENATOR FROM MISSOURI, DATED ST. LOUIS, JANUARY 24, 1874.

MY DEAR SIR: I expected to be in Washington before this, to explain to you everything connected with my intended proposition to deepen one of the passes of the Mississippi, for a given sum of money to be paid by the Government *after* the work is done. I have, however, been so much occupied with matters connected with the Bridge that I have found it impossible to complete the bill for presentation to Congress, and to visit the capital. I see no possibility of being in Washington within two weeks, and therefore wish you to know that I am in earnest in this matter, and intend having such a proposition presented for the consideration of the Government.

Of course the novel method of undertaking this work on the principle of "no cure, no pay," prevents the possibility of spending any money in the lobby, or anywhere else, to secure the passage of the bill, and I can only hope for its favorable consideration and advocacy by those senators and representatives who realize the magnitude of the benefits which will accrue to the whole country, and especially to the Valley of the Mississippi, if I am successful, and who are really sincere in their wish to give this river a proper outlet to the sea.

I do not propose to defeat the St. Philip Canal scheme, but to prove, at the risk of myself and associates, that it is practicable to have a reliable and capacious channel, with twenty-eight feet of water in it, from the river into the gulf, in less than half the time

that the proposed canal can be built. If the canal appropriation be made, and we *fail*, no possible harm or cost can come to the country. If we succeed, however, we will demonstrate that no further appropriations are required for canal schemes; while the total cost of my plan, to the Government, will be much less than the *estimated* cost of the canal, and far less than its actual cost.

In brief, my proposition will be the chartering of a company, to be called "The National Improvement Company," with authority to undertake, at its own risk and cost, the erection of such works as it may deem needful to secure a permanent and reliable depth of twenty-eight feet, with a channel-way of not less than six hundred feet wide, from the Mississippi into the Gulf, through such pass as it may select; the said work not to interfere, whilst being constructed, with the free navigation of said pass.

The bill will provide for the payment of $5,000,000 to the company, when this depth shall be attained; $2,000,000 of the sum to be due when a clear depth of twenty feet shall be secured, and the remainder in proportion as the maximum shall be established. It will likewise provide for the payment of one-tenth of the above cost, or $500,000, every year thereafter for ten years, provided that during each year the maximum depth shall have been maintained in said channel.

I shall have no difficulty whatever in convincing you, when I see you, that my theory respecting the control of the current, and the certainty of accomplishing the desired result by the intended method, cannot be doubted when understood. I shall be gratified and obliged by your informing such senators as you may chance to converse with, on the improvement of the Mississippi, of the above facts.

With great regard, I am, dear sir,

Very sincerely, etc.,

JAMES B. EADS.

LETTER

To Hon. Wm. Windom, United States Senate, Chairman of Committee on Transportation Routes to the Seaboard, dated St. Louis, March 15, 1874.

Dear Sir: The improvement of the mouth of the Mississippi, proposed by me, consists in an artificial extension of the natural banks of one of the passes, from the point where they commence to widen and disappear in the Gulf, to the crest of the bar, about five miles distant.

This method is indicated as the only proper one by the following facts:

The Mississippi is simply a transporter of solid matter to the sea. This consists chiefly of sand and alluvion, which is held in suspension by the mechanical effect of the current. A small portion, consisting of larger aggregations, such as gravel, boulders, small lumps of clay, and drift wood, is rolled forward along the bottom. By far the greatest portion is, however, transported in suspension. The amount of this matter, and the size and weight of the particles which the stream is enabled to hold up and carry forward, depend wholly upon the rapidity of the stream, modified however, by its depth. The banks and bottom being chiefly sand and alluvion, are easily disintegrated by the movement of the water, hence the amount of load lost by any slacking of the current at one place will be quickly recovered in the first place below where the current is again increased.

The popular theory advanced in many standard works on hydraulics, to wit, that the erosion of the banks and bottom of streams like the Mississippi is due to the *friction* or *impingement* of the current against them, has served to embarrass the solution of the very simple phenomena presented in the formation of the delta of the Mississippi, because it does not explain why it is that under certain conditions of the water it may develop, with a gentle current, an abrading power which, under other conditions, a great velocity cannot exert at all. A certain velocity gives to the stream the ability of holding in suspension a proportionate quantity of solid matter; and when it is thus charged, it can sustain no more, and hence will carry off no more, and therefore cannot then wear away its bottom or banks, no matter how directly the current may impinge against them.

In the upper portions of the delta (which, according to some writers, extends a few miles above Cairo), the width of the river is very irregular. When a rise occurs, the current is increased in the narrow parts of the river, and the carrying capacity of the stream consequently becomes greater, and it at once takes up an additional load. When, however, as the stream flows on, it enters a wide expanse, the current is slackened and the excess of load is dropped to the bottom, and thus shoals or bars are formed. From such expansion of channel way the volume of water, thus relieved of a portion of its load, passes into another one of the narrow parts of the channel, and here its current, by contraction, is again accelerated, and the increased load which it can carry is immediately scoured up from the bottom and sides of the channel. In the bends the centrifugal force of the water makes the current more rapid on the concave bank of the stream, and there it usually gets its additional load, and the caving in of the bend testifies to the rapacity of the water at that point of its course. Once loaded, however, it can carry no more, and hence it may sweep around half a score of other bends below, with equal velocity, without injury to them. If it encounter another expanse, however, it again loses part of its velocity, and with it part of its load, to be recovered again in the narrower parts of its channel below. It is evident, therefore, that if the channel were at all uniform in size, the current would be more constant, and the alternate depositing and recovery of part of the burden of the stream would be prevented. This loading and unloading is synonymous with caving banks and sand-bars.

The lower part of the river, nearly all the way from Red River to the mouths of the passes, is remarkably uniform in width, and is, therefore, comparatively free from falling banks and shoals. This part of the river is transporting its load with great regularity, and without interruption, to the sea; whilst that above, owing to the alternating contractions and expansions in its channel, transports its burden with great irregularity, dropping a part here and taking up a part there, and thus by successive stages, from season to season, it is borne forward.

If the volume of water were constant, it is plain that the river would soon have a current of great regularity; because the deposit dropped in a wide part of the river lessens the capacity of the channel there, by shoaling it, and re-establishes the proper velocity of current, and thus stops further deposit at that place; whilst at the contracted channel the scour soon enlarges the passage, and consequently reduces the current, and thus further scour ceases at that point.

In a channel of uniform width, when the river falls, the stream occupies only the narrower parts of it, and if these be still too great to maintain sufficient current to transport the load, the excess is de-

posited in the channel, which is thus further diminished until the current is thereby accelerated to the proper rapidity, after which it ceases to deposit any more. When the Bonnet Carré crevasse occurred, the river below it (one hundred and seven feet in depth), was shoaled up thirty-one feet, because the volume of water in the river, being lessened by the crevasse, was no longer sufficient to maintain the normal current in a channel large enough to carry the entire river, consequently the current below the crevasse slackened, and the excess of load was dropped in the channel until the bottom was filled up thirty-one feet deep with the deposit. This reduction of channel was sufficient to re-establish the current and prevent further deposit.

We see, therefore, that the causes which control the speed of the stream, and those which give to it the ability to hold its burden of solid matter in suspension, are constantly acting in opposition to each other, and thus the equilibrium between them is restored as often as it is disturbed by alternations in volume, or by irregularities in channel.

We not only learn from this how simple some of the most apparently mysterious phenomena of the river really are, but also how futile it would be to attempt either to enlarge or to diminish the normal size of its channel, anywhere within its alluvial bed. As rapidly as the engineer strives to deepen it without proportionately contracting it, and thus enlarges it beyond the capacity which these natural forces give it, just so rapidly will the current be slackened by the enlargement, and the deposit be dropped there, and thus lessen it again. And as fast as he may contract it, just so fast will the current be increased, and the consequent scour enlarge it again by deepening it. The *magnitude* of the channel is determined by forces which it is neither necessary nor profitable for the engineer to encounter. The *form* of the channel he can control and alter. If he widen it, these forces will inevitably shoal it; if he contract it, they will just as certainly deepen it.

Rèvy, in his recent valuable treatise on "Hydraulics of Great Rivers," declares that the current is doubled by doubling the depth, and trebled when it is three times as deep—the inclination of surface being the same. The cause of this is owing to the reduced amount of frictional surface of the bottom and sides of the channel, where the stream is narrow and deep; and it explains why the shore current of the river is less rapid than the central current—the latter having less friction in proportion to its volume, the gravity of water in that part acts with less resistance.

The phenomena presented by the protrusion of the passes of the river out into the gulf are equally as simple as those of the river above. A glance at the map shows how remarkably uniform is the width of each of them from their commencement until they reach the neigborhood of the gulf. In the passes, and in the river for several

hundred miles above, the slower shore currents have dropped their excess of load, until the shores have been built up and narrowed in, to such a degree that all further deposits by them tend to increase the steepness of the banks; hence the additional deposit slides down towards the middle of the channel bed as fast as it is dropped. The onward motion of the stream tends to continually draw in its waters from the shore (which is evidenced by the drift-wood flowing always in the middle of the channel of the stream); hence the water, after depositing part of its load near the shore is again made capable of carrying it by the increase of its velocity, when it again gets near the middle of the stream, and thus the central mass of water is continually made capable of taking up from the bottom the excess of load dropped by the shore currents. At the mouth of the pass this is not the case, for the angle of rest of the deposit, or the natural slope, is not yet attained there. At the Southwest Pass, for instance, after flowing for several miles through a deep channel, with narrow and parallel banks, the stream widens out from about twelve hundred feet and a depth of sixty feet, to ten thousand feet, and a depth on the centre of the bar of about fifteen feet. Here the shore currents are continually dropping the surplus load which their diminished velocity is unable to hold up, and thus the shores of the Pass are being constantly built up and narrowed in, and brought to the surface of the water, where, with reed grass, marine plants, etc., they are gradually converted into dry land.

The strong central current, however, is maintained intact by the reduced depth over which the stream passes, as it expands, like a fish's tail, out to the bar. The velocity of the stream being maintained by shoaling in depth as it expands in width, it is able to transport its entire load out beyond the bar, excepting only that which it has dropped on the submerged and incipient shores of the Pass. Although the current is strong out across the bar, it is soon checked because of its immense width and shallow depth, by which great friction in proportion to volume is induced. Hence the load is deposited just outside the bar, and its constant outward growth is thus assured, while the growth of the shores of the Pass follow in due order.

The fact that a given current will keep in suspension a corresponding quantity of solid matter; that at a less velocity a portion of it will be deposited and taken up again at a greater, is fully recognized in experimental science, and has been extensively made use of for analysis of soils. An eminent investigator of this subject, Prof. E. W. Hilgard,* of the University of Michigan, has classified silts according to the different velocities at which they deposit. This independent line of research fully confirms the view herein advanced in explanation

* See American Journal of Science, October, 1873.

of the phenomena presented throughout the alluvial bed of the Mississippi.

It is a popular fallacy to imagine that the gulf presents a barrier to the onward flow of the stream at the mouth of the Pass. On reflection, it must seem reasonable that a river should flow with less friction between walls of water than between walls of earth. At the bar the river has its banks of earth no longer, but it still flows between banks of salt water, and over a bottom of brine instead of mud. It has no longer a descent of a few inches to the mile, however, and hence must maintain its current in the gulf simply by its momentum. Friction on its sides and bottom is the agent which finally brings it to rest; but while its momentum lasts, the widening out into the sea and the final obliteration of the river will proceed very gradually.

If from the point where the banks of the pass be twelve hundred feet asunder, and its depth sixty feet, we should artificially prolong them to the crest of the bar, still keeping them but twelve hundred feet asunder, we would inevitably have sixty feet depth at the mouth of these jetties. A thorough comprehension of the laws which control the river, will banish from the mind of any one the erroneous idea that the construction of the jetties will back up the water, and thus raise it above them. It will also demonstrate that to be successful the jetties should be parallel, not converging.

As doubling the depth doubles the current with the same inclination of surface, it must be evident that the great reduction of friction accomplished by narrowing the channel from ten thousand to twelve hundred feet will enable the momentum of the stream to be kept up to a greatly increased distance beyond the bar, and hence the river will be able to carry to greater depths, and into stronger gulf currents, that load which it is now only able to deposit just outside of the bar. That a stream will preserve its individuality for a great distance, while flowing through the sea or through another body of water, can be proven by every river which enters the ocean with a strong and consequently deep volume. The upper Mississippi preserves its identity for a score of miles after having entered the grand channel of the main river, and the dividing line which separates its clear waters from those of its more powerful neighbor can be distinctly traced, in flood time, far below St. Louis.*

If the truth be once impressed on the mind, that the river maintains for some distance a distinctive channel through the gulf, the effect of the feeble tides at the mouth will be more clearly comprehended. These average less than fourteen inches in height, and while they simply act

* During a calm day and large discharge, river water can be obtained for many miles outside the bar, on the surface, and to a depth below equal to the mean depth of the bar. (Humphreys and Abbott, Physics and Hydraulics of the Mississippi River. Appendix, page 18.)

to raise and lower the fluid channel through which the river flows after leaving the land, they really oppose no barrier to its onward progress. The average velocity of the current is maintained; the retardation due to the flood tide being compensated by the increased speed induced by the ebb.

A careful study of the above facts should serve to banish all fear of a progressive advancement of the bar beyond the jetties. That the deposit of the river must tend to shoal the water beyond the mouth, and ultimately to fill up the gulf itself, is certain; but that it can form a shoal in front of the jetties, in this or the next generation, is scarcely possible. If the stream at the Southwest Pass be made to emerge in a compact form from betwen the jetties into the gulf, it is not unlikely that its course and current will be distinctly marked fifty miles from the present bar. Even now it is said that the river current can be detected twenty-five miles from the passes. The Coast Survey soundings show that it is but a mile and a half from the bar out to a depth of one hundred and twenty feet, and but three miles to two hundred feet, and two hundred miles from the passes it is ten thousand feet deep.

The solution of the problem of of improving the navigation between the river and gulf will never be satisfactorily accomplished except by jetties, and that they will ultimately be resorted to is as certain as that commerce and agriculture will increase in the Valley. No canal with locks will answer the demands of navigation even in the near future. Engineering skill and experience are fully competent to overcome all the difficulties presented by the unstable and treacherous bottom on which the jetties must rest, so that they shall defy the floods of the river and the storms of the sea. It is for the Congress of the United States to determine whether I shall be permitted, at the sole risk of myself and associates, to demonstrate the entire practicability of speedily securing a deep and permanent outlet for the river.

Very respectfully,

James B. Eads.

CANAL AND JETTIES COMPARED.

THE FORT ST. PHILIP CANAL.

CAPACITY.

It requires about twenty minutes in moderate-sized canals to pass a single boat through a lock; but for large ships, the time requisite to open and close the enormous lock gates of the proposed canal could not be much less than an hour, including the hauling of the ship into and out of the lock. But even supposing it required half so long, it could then pass but twenty-four vessels per day out of the river, and as many more into it. Such a canal would scarcely suffice to pass out the number of steamships now leaving New York daily, to say nothing of the multitude of sailing vessels arriving and departing every twenty-four hours. If it could be completed in ten years, it would be then found that it had not one-quarter the capacity it would need; and this too, supposing no dredging or repairs should interrupt its constant use.

This fact is partly conceded by its advocates, as they propose that small vessels, of 10 or 12 feet draught, shall encounter the shoals and dangers of the present natural outlet, thus virtually admitting that the capacity of the canal would be insufficient to wholly relieve navigation from its present dangers and delays.

INTERRUPTIONS BY DREDGING, ETC.

The entrance basin, 400 feet long between the river and the lock, would be constantly receiving the deposits of the river, in consequence of the current flowing past it, and would be a continual source of annoyance and delay from this cause.

In the report of the U. S. Engineers on the canal (Ex. Doc. 113), it is admitted that dredging will be absolutely necessary. On page 10 the report says of the Gulf end of the canal:

"As there will be no current through the canal, we must expect silting immediately between the heads of the jetties, due to eddies from the currents through the pass. It is apprehended that shoaling of the entrance to the canal from this cause will not be rapid, but

that there will be required, to free the entrance from such deposit as may be made, each year, the services of an ordinary dredge-boat for several days, perhaps weeks."

And of the lock and fore-bay or basin, next to the river, it says, on the same page:

"Slight deposit is anticipated within the lock, the removal of which, quarterly or semi-annually, will be a very simple operation.

"There will be deposit of river silt in the fore-bay of the lock, due to an eddy from the river current. The amount of this deposit can not be calculated, and it will require occasional dredging to maintain the depth of this entrance to the canal."

While its most enthusiastic advocates make these admissions respecting the inevitable necessity of dredging the east and west ends of the canal and its lock, we may well pause to consider the effects that would result from checking commerce in its flow to and from the vast and productive valley of the Mississippi every time a few days or weeks were required to dredge out the fore-bay, or the lock, or to make repairs to lock gates and sills, and the like, or to remove the silt from the jetties in Breton Bay.

LOCATION UNDETERMINED.

With reference to the location of the canal, the report declares, on pages 62-3:

"But it is suggested, in order to avoid beds and pockets of quicksand known to exist at some points in this locality, that the precise line of the canal should not be decided upon until a more thorough examination of the sub-strata has been made by borings. It is not improbable that such an examination may indicate the expediency, and perhaps the necessity, not only of adopting a curve, or a series of curves, in preference to a straight line for the axis of the canal, but also of selecting other points of termini than those recommended by Captain Howell."

And on page 64:

"8. It is evident from the foregoing that the necessary and unavoidable absence of sufficient data to determine the best location for the line of canal across the peninsula, including its termini, and particularly its debouche by jetties into Isle au Breton, renders it impossible to make a close estimate of its cost."

THE ULTIMATE COST IS UNKNOWN.

The question of ultimate cost of the work is equally as indefinite as that of location. On this subject, in addition to the last extract, the report declares (page 63):

"2. With regard to the plan submitted by the engineer in charge, he has stated that it was prepared while pressed with other important duties, and that, under the circumstances, it was not possible to perfect all details of the project, or to make the numerous borings which are considered a necessary preliminary to a precise location of the route of the canal through the entire length. The estimate submitted can therefore only be regarded as an approximation to the probable cost of the work."

On page 64, the report also says, with reference to this subject:

"7. The jetties, extending the canal into the deep waters of Isle au Breton Pass, will doubtless require more material than the plan submitted by Captain Howell contemplates; but inasmuch as the length of these jetties, and their cubic contents, depend, to no inconsiderable extent, upon the position selected for them, no very accurate estimate of their cost can be made until the final location is determined upon."

These quotations are all taken from the *majority report*, which favors the canal project.

THE PLANS OF THE CANAL NOT MATURED.

From these extracts it must be evident that General Barnard's emphatic declarations against the scheme are entirely justified. He says (page 89):

"Surely there is ground here, especially when we weigh the inestimable benefit of an open river mouth, to pause at least long enough for a mature study and investigation, not merely on paper, but by surveys and measurement at the localities, to collect the special data which bear upon the application of the project to them, instead of, by a hasty prejudgment founded on inadequate knowledge, deciding that there is no remedy to the evils but the gigantic and costly alternative of a ship canal."

It is evident, therefore, from the report, that neither the cost of the work, the line of its location, the position of its terminal points,

nor the exact methods of construction, have been determined upon by the engineers who advocate the work.

General Barnard, who was the President of the Board, after expressing his faith in jetties as the speediest means of obtaining a permanent deep-water channel, thus protests against the canal, on page 91 of the report:

"It is said that 'the time has come' when the needs of commerce demand the canal; but I answer, that the *time will come* when there will be the same cry for a navigation unimpeded by locks—AN OPEN RIVER MOUTH—which we now hear for a canal. But in whatever aspect the question be regarded, the use of the river mouth for the next ten years is simply inevitable.

"The conditions of the location and execution of a canal have received no adequate study. The plan, boldly and ably, and yet so imperfectly sketched out nearly forty years ago by one for seventeen years my commanding officer or professional associate, W. H. Chase, is yet, in its engineering features, the best plan extant; and the grave objections to that apply with even greater force to the present project, and demand new studies of location and an entire revision of plans of execution. It would be a rash confidence which would contemplate a realized 'Fort St. Philip Ship Canal' earlier than A. D. 1884."

AN OPEN RIVER MOUTH.

With regard to the improvement of the mouth of the river by jetties, the Board do not presume to say that they will not deepen the channel. It is simply the difficulty of constructing the jetties, and the necessity (as they believe) of extending them every year, which constitute the chief objections to the system.

General Humphreys says (page 2 of the report):

"After a careful investigation of the question of applying this method of improvement to the mouth of the Mississippi River, I am of opinion that it does not present, either in its construction or cost, superior advantages to the canal plan. One of the chief objections to the jetty system is the unavoidable necessity of constantly extending the piers in the open sea, exposed to the full force of storms."

In a letter addressed last May to Mr. J. H. Oglesby, President of the Chamber of Commerce of New Orleans, Capt. C. W. Howell, United States Engineers (a member of the Board to report upon the

canal, and the officer who designed the present canal plans), makes the following statements respecting the jetty system:

"The theory is attractive from its apparent simplicity, and for the same reason is the first to claim the attention of dabblers in hydraulic engineering, who either do not know, or else lose sight of the conditions essential to its successful application. The principal of these conditions are two. 1st. That the character of the bed and banks of the river, at the point of application, be such that scouring will be effected in the bed, in preference to the banks; in other words, the banks must be firm enough to withstand the action of the current, and the bottom yielding enough to permit scour.

"The second condition is, that there shall exist a current (littoral) passing the outer extremity of the jetties perpendicular to them, capable of sweeping to one side or the other all deposit made about the jetty heads and tending to form a new bar outside. No such current has been discovered at the mouth of the Mississippi, although carefully sought for. In default of it, jetties would have to be built further and further out, not annually, but steadily every day of each year, to keep pace with the advance of the river deposit into the Gulf, provided they are attempted, and the attempt warranted by having the relative character of bed and banks favorable.

"For the reason that these two conditions are not to be found at the mouth of the Mississippi, careful engineers have time and time again pronounced the application of jetties at either Southwest Pass or Pass a l'Outre not worthy of trial *at Government expense*. If enthusiastic jetty men wish to pass from theory to practice, they can always gain consent to spend *their own money* in building jetties at Southwest Pass, and if they succeed in doing good they will have fair claim on Government for recompense. * * * *

"Jetties have once been attempted there, and not only reported a failure by the inspecting officer, but abandoned by Messrs. Craig and Rightor, who made the attempt. The full particulars of this may be found in Ex. Doc. No. 5, Ho. of Reps., 36 Cong., 2d Sess. The practical experience gained by that failure, I presume, will deter the Government, though it may not deter adventurous jetty men, from sinking more money in such attempts."

Capt. Howell was doubtless not aware that he was making three misstatements in his letter to Mr. Oglesby. They are as follows:

1st. That there are no currents capable of sweeping to the one side or the other the river deposit beyond the proposed jetties.

2d. That "careful engineers have time and time again pronounced the application of jetties at these passes unworthy of trial *at Government expense*."

3d. That the jetty system has once been tried at the Southwest Pass and proved a failure.

These statements have been so often repeated inadvertently by other zealous advocates of the canal, whose official standing entitles their assertions to respect, that it is not surprising a community, when educated to believe them, should hesitate to place confidence in the jetty system.

The following paragraph from the elaborate report of Humphreys and Abbott (Phys. and Hyd. of the Mississippi River), page 449, completely disproves the first statement:

"The investigations of the Coast Survey have also shown that the tidal wave approaches the mouths of the Mississippi from a southerly direction. With this tidal wave there is near the coast a tidal current in the same direction. The tidal wave lifts up the river current in the gulf, and the tidal current passes under it, though checking it to some extent in so doing. The direction of this tidal current is modified by its contact with the river current, and to a greater degree by its contact with the outer slope of the bar deposit. In the case of the Southwest Pass, a flood tide brings a current from the southeast, which is changed to a southwest direction, more westerly than that of the river current, by the bar deposit along the eastern side of the mouth of the Pass. The ebb tide is accompanied by a current from the opposite direction, which is similarly diverted by the deposit on the western side of the mouth of the Pass, the direction being more southerly than the current of the river. Winds may change the direction and force of these currents, which, in mid-river current, at a depth of forty feet, are shown by the observations to vary from three-tenths of a foot to two and five tenths feet per second, the mean being about five-tenths of a foot. *As a velocity of five-tenths of a foot per second is sufficient to transport the material of which the bar is formed, the action of the gulf currents in carrying into deeper water the material pushed by the river into the gulf is evident.*"

The italics, which are not in the report, are used here to impress these facts more fully on the memory of those who have been continually making counter statements.

The following extract from the same work (being a foot-note on page 445), disproves the other two statements made by Capt. Howell:

"Attention should here be directed to the fact that *the plan of jetties has not really been tried at the mouth of the Mississippi*, as the contractors merely built one insecure jetty of a single row of pile planks, about a mile long, whereas the Board of 1852 recommended jetties five miles long on each side of the channel, each fourteen and a half feet wide,

composed of piles two feet apart. The plan has been tried, however, at the principal mouth of the Rhone, a delta river like the Mississippi, and has effected the desired increase of depth."

The Board referred to by Humphreys and Abbott, in this paragraph, was composed of Capt. Latimer, Capt. Chase, and Gens. Barnard and Beauregard. We see, therefore, that "careful engineers" *have recommended* the trial of the jetty system for the mouth of the Mississippi, and prior to the date of Capt. Howell's letter we believe no engineers of note had reported against them.

COST OF JETTIES.

The cost of constructing jetties to insure twenty-five feet of depth, is estimated in the report of the U. S. Engineers, on page 73, as follows:

"This consideration of the unstable and treacherous nature of the shoals and banks is necessary in order to fix the mind upon the cost and risk, as well as upon the dispppointment which would likely attend an attempt, upon such foundations, to construct works to coerce or control the currents of the passes.

"An estimate has been prepared by Capt. Howell, engineer in charge, of the jetties described in this report, supposing them to rest upon the natural bottom, without settlement, as follows:

Fascines and ballast, at $5.00 per cubic yard	$2,545,220 00
Riprap stone, at $7.90 per ton	2,241,097 60
Total	$4,786,317 60

"If settlement and the other probabilities enhancing the cost of this work, as already discussed, be considered, it appears entirely within limits to state that the above estimate should be doubled."

This would make their cost $9,472,635.20, and to this the Board deem it proper to add the cost of an additional 1,000 feet of extension that would be necessary, estimating that the bar would advance 250 feet per annum, and that four years would be required to complete the jetties, making a grand total largely over $10,000,000.

The cost of the annual extension of the jetties the Board declares would be $1,613 per linear foot, or for 250 feet $403,250 for each jetty, or $806,500 per annum for this expected advance; or, in addition to

the first cost of the jetties, $7,249,500 more, for annually extending them during nine years.

This estimate, although for only 25 feet of depth, is more than double that which is by the terms of House bill No. 2342, to be paid for constructing jetties for 28 feet depth, and for maintaing them for nine years after their completion.

EXTENDING THE JETTIES WILL BE UNNECESSARY.

On page 88 General Barnard combats the idea that there will be any advance of the jetties necessary after they are built. In this view he is supported by the experience at the Danube, where the depth has been increased by jetties from nine to twenty feet, and no advance, so far, is indicated. On the contrary, the shore-line has actually receded near the jetties. He is also sustained in his opinion on this subject by some of the most eminent engineers in Europe and America.

The amount of solid matter discharged from the Southwest Pass in one year, is estimated in Humphrey and Abbott's report as being equal to one mile square, and nine feet deep. As the water is two hundred feet deep three miles from the bar, if all this deposit could be concentrated and dropped on one square mile there, and made to form a prism of that base, it would require eighteen years to build it up within twenty feet of the surface.

By narrowing the channel the depth is proportionately increased. If the depth be doubled (the volume and inclination of surface remaining unchanged), the speed will be doubled.* If the speed be doubled by doubling the depth between the jetties, or trebled by increasing the depth threefold, it must be evident that the stream will maintain its momentum through the gulf waters to more distant and greater depths, and thus the re-forming of a bar in front of the jetties will be indefinitely delayed.

That the current is increased in proportion as the depth is increased, is because the surface of the river bed in contact with the stream is proportionately diminished. The friction of the river bed is the cause of the retardation of the current, gravity being the force which creates the current. When the stream enters its level bed in the gulf, which it is known to occupy for many miles out, it is impelled solely by the momentum imparted to it by gravity, and of course, the more rapidly it emerges from the jetties, the more distant in the gulf will be the point of equilibrium where the impelling and retarding elements, gravity and friction, cease to act, and where the river comes to rest and is obliterated. Just in proportion as it loses its velocity

* See Hydraulics of Great Rivers, page 22 (Revy.)

will it drop its deposit. The heavier portions will be swept to the one side or the other by the tidal currents passing transversely under the river bed in the gulf, and which are referred to in the quotation on page 8 from Humphreys and Abbott.

The gulf stream sweeps around the gulf, entering by the Carribean Sea, and emerging with great velocity by the Florida capes, follows the North American coast to Newfoundland. It passes not far south of the mouths of the Mississippi, and it is not impossible that, with an accelerated current from the passes, after completing the jetties, it may distribute the mud of Missouri and Illinois on the coast of the Carolinas and New England.

PROFESSIONAL OPINIONS.

The advocates of the canal place great stress upon the fact, that six out of the seven officers of the United States Engineer Board recommend the canal, whilst but one, the senior member, opposes it. His reputation among both civil and military engineers is acknowledged in Europe and America to be equal to that of any other one living, and we have no evidence that he does not reflect the views of a majority of his corps upon this important question. As an evidence, however, that General Barnard is not unsupported in his opinion upon the value of jetties for improving the mouth of the Mississippi, letters from distinguished engineers are appended.

COMPARISON OF COST.

The estimated cost of the canal by the United States Board of Engineers exceeds $10,000,000. In addition to the uncertainty of this amount completing it, there will still be the cost of maintenance when completed. This would probably equal $500,000 per annum. Hence, for the canal and nine years' maintenance the cost would be $15,000,000, or $5,000,000, in excess of the open river mouth; while the value of the latter would be infinitely greater than the canal.

The proposal to build and maintain the jetties for nine years for $10,000,000 is but one-half of the estimated cost for jetties, including nine years' maintenance of them, as computed by the United States Board of Engineers; and, in addition to this saving, the United States would be certain that they would cost *only* one-half of the estimate of the United States Engineers, and that they would even then not have to be paid for unless successful.

April, 1874. JAMES B. EADS.

CORRESPONDENCE

WITH BUSINESS MEN OF NEW ORLEANS.

J. B. Eads, Esq.

DEAR SIR: We the business men of New Orleans have noticed with regret your proposition to Congress, to improve the water at the mouth of the Mississippi river by your *jetty system*. We most respectfully ask you to *wtihdraw* the same, as it will only serve to embarrass and delay *permanent* work there as recommended by the Board of United States Engineers and our Chamber of Commerce. It also helps to delay action by our northern and eastern enemies to any improvement.

Our objections to your jetties are: First, they will not stand against worms and will be readily undermined by the current; second, it will be no protection against a *continual extension* of the *bars*, and of no permanent use.,

L. J. HIGBY,
Pres't N. O. E. and W. H. Co.,
A. K. MILLER & CO.,
Ag't State Line S. S. Co. Line,
CHAS. BRIGGS,
Pres't Louisiana Mut. Ins. Co.,
JAMES T. TUCKER,
Gen. Ag't M. Central R. R.,
J. H. OGLESBY,
J. T. BURDEAU,
Ag't Miss. V. T. Co.,
SILAS WEEKS & CO.,
Ag't and D. S. S. Co.,
CHAS. E. SLAYBACK & CO.,
Commission Merchants,
GLOVER & ODENDAHL,
WM. FLOOD,
J. A. WALSH.
CHAS. PLEASANTS,
FOLGER & CO.,
J. T. BELKNAP & CO.,
MARSHALL J. SMITH,
P. R. FELL,
W. M. SMALLWOOD,
W. H. BOFINGER,
A. MARTIN,
C. KOHN,
ARCH. MONTGOMERY,
EDM. J. FORSTALL SONS.
SAML. H. KENNEDY,
ALBERT BALDWIN,
AUSTIN W. ROUNTREE,
G. T. BEAUREGARD,
DECAN, ZEREGA & CO.,
Agents Liverpool S. S. Line.

New Orleans, March 18, 1874.

WASHINGTON, April 6, 1874.

Messrs. Higby, Oglesby, Beauregard and others.

GENTLEMEN: I have the honor to acknowledge receipt of your letter of the 18th ultimo, asking me to withdraw my proposal to the Government for deepening one of the outlets of the Mississippi.

This request is based upon a misconception of facts. The people of New Orleans have not been permitted, through its press, to hear both sides of the question at issue between us. They have been educated to believe the misstatements of zealous advocates of the canal, while the disproof of their arguments and assertions has found no place in your journals. I endeavored to correct these misstatements through one of the papers in your city, but my letter was suppressed. A pamphlet addressed to Senator Windom, explaining the theory on which my plan of improvement was based, was sent to make its first appearance in New Orleans; but this pamphlet, only eight pages long, had its beginning and ending cut off, and just enough of the remainder published to confuse the reader.

The people of your city have been taught to believe that there are no currents at the passes capable of sweeping to the one side or the other the river deposit, hence the bar will continually advance; that the jetty system has once been tried at the Southwest Pass and was a failure; that careful engineers have time and again reported against the use of jetties there; that the bar was so tough and tenacious that the current could not abrade it, and yet so soft and unstable that jetties would sink down in it or be undermined as fast as constructed. These assertions have been repeated over and again so often in your city that I am not surprised you should believe them, for they have been advanced by those whose position is such as to entitle their statements to profound respect. Here, before the committees of the Senate and House, however, I have had an opportunity of refuting them in the presence of the distinguished gentlemen representing your Chamber of Commerce, who repeated them, while urging the canal project. The opportunity to be heard before unprejudiced gentlemen in the National Legislature, has resulted in securing unanimous reports from the committees, both in the House and Senate, in my favor. I only ask of the people of New Orleans an equally impartial hearing.

To show that I am justified in stating that your people have been taught to believe what is not true respecting the jetty system, I will call your attention to the following extracts from a letter addressed last May, by Capt. C. W. Howell, United States Engineers, to Mr. J. H. Oglesby, President of the New Orleans Chamber of Commerce. Speaking of the jetty system, Capt. Howell says:

"The theory is attractive from its apparent simplicity, and for the

same reason is the first to claim the attention of dabblers in hydraulic engineering, who either do not know, or else lose sight of the conditions essential to its successful application. The principal of these conditions are two. 1st. That the character of the bed and banks of the river, at the point of application, be such that scouring will be effected in the bed, in preference to the banks—in other words, the banks must be firm enough to withstand the action of the current, and the bottom yielding enough to permit scour.

"The second condition is, that there shall exist a current (littoral) passing the outer extremity of the jetties perpendicular to them, capable of sweeping to one side or the other all deposit made about the jetty heads and tending to form a new bar outside. No such current has been discovered at the mouth of the Mississippi, although carefully sought for. In default of it, jetties would have to be built further and further out, not annually, but steadily every day of each year, to keep pace with the advance of the river deposit into the gulf, provided they are attempted, and the attempt warranted by having the relative character of bed and banks favorable.

"For the reason that these two conditions are not to be found at the mouth of the Mississippi, careful engineers have time and time again pronounced the application of jetties at either Southwest Pass or Pass a l'Outre, not worthy of trial *at Government expense*. If enthusiastic jetty men wish to pass from theory to practice, they can always gain consent to spend *their own money* in building jetties at Southwest Pass, and if they succeed in doing good, they will have a fair claim on Government for recompense. * * * * *

"Jetties have once been attempted there, and not only reported a failure by the inspecting officer, but abandoned by Messrs. Craig and Rightor, who made the attempt—the full particulars of this may be found in Ex. Doc. No. 5, Ho. of Reps., 36 Cong., 2nd Sess. The practical experience gained by that failure, I presume, will deter the Government, though it may not deter adventurous jetty men, from sinking more money in such attempts."

Capt. Howell was doubtless not aware that he was making four misstatements in his letter to Mr. Oglesby. They are as follows: 1st. That the banks of the passes will scour away sooner than the bed of the stream. 2nd. That there are no currents capable of sweeping to the one side or the other the river deposit beyond the proposed jetties. 3rd. That "careful engineers have time and time again pronounced the application of jetties at these passes unworthy or trial *at Government expense*." 4th. That the jetty system has once been tried at the Southwest Pass and proved a failure.

The idea that the banks will be scoured away is based upon the false assumption that the water will be permanently raised above the jetties. If this were true it would simply create the effect of a flood, and

those who are not engineers know that the way the banks of the passes are built up above the ordinary surface level of the river, is by the overflows. Where there are no levees every overflow contributes to the elevation of the bank of the stream. Each time the banks of the passes are overflown, the reed-grass and plants on their marshy surfaces not only prevent abrasion, but they check the flow of the current and cause the sediment which is held in the water to be dropped on the banks. With parallel jetties five miles in length, it would be impossible to raise the water five inches, and any temporary elevation would subside with the deepening of the channel.

Capt. Howell's first statement is therefore evidently an error. The following paragraph from the elaborate report of Humphreys and Abbott (Phys. and Hyd. of Mississippi River), page 449, completely disproves his second statement:

"The investigations of the Coast Survey have also shown that the tidal wave approaches the mouths of the Mississippi from a southerly direction. With this tidal wave there is near the coast a tidal current, in the same direction. The tidal wave lifts up the river current in the gulf, and the tidal current passes under it, though checking it to some extent in so doing. The direction of this tidal current is modified by its contact with the river current, and to a greater degree by its contact with the outer slope of the bar deposit. In the case of the Southwest Pass, a flood tide brings a current from the southeast, which is changed to a southwest direction, more westerly than that of the river current, by the bar deposit along the eastern side of the mouth of the pass. The ebb tide is accompanied by a current from the opposite direction, which is similarly diverted by the deposit on the western side of the mouth of the pass, the direction being more southerly than the current of the river. Winds may change the direction and force of these currents, which, in mid-river current, at a depth of forty feet, are shown by the observations to vary from three-tenths of a foot to two and five-tenths feet per second, the mean being about five-tenths of a foot. *As a velocity of five-tenths of a foot per second is sufficient to transport the material of which the bar is formed, the action of the gulf currents in carrying into deeper water the material pushed by the river into the gulf is evident.*"

The following extract from the same work (being a foot-note on page 455), disproves the other two statements made by Capt. Howell:

"Attention should here be directed to the fact that *the plan of jetties has been really not tried at the mouth of the Mississippi*, as the contractors merely built one insecure jetty of a single row of pile planks, about a mile long, whereas *the Board of 1852 recommended jetties* five miles long on each side of the channel, each fourteen and a half feet wide, composed

of piles two feet apart. The plan has been tried, however, at the principal mouth of the Rhone, a delta river like the Mississippi, and has effected the desired increase of depth."

The italics, which are not in the report, are used here to impress these facts more fully on the memory of those who have been continually making counter statements.

The Board referred to by Humphreys and Abbott, in this paragraph, was composed of Capt. Latimer, Capt. Chase, and Gens. Barnard and Beauregard. We see, therefore, that "careful engineers" *have recommended* the trial of the jetty system for the mouth of the Mississippi; and prior to the date of Capt. Howell's letter we believe no engineers of note had reported against them.

Humphreys and Abbott were certainly justified in saying that "the plan of jetties" had not been tried there; for all engineers know that the application of that system to any river mouth opening into the sea as the Mississippi does, with no banks above water, absolutely involves the construction of *two* jetties, one on each side of the stream; only *one*, however, an insecure pile plank dam on *one side* of the mouth seems to have been sufficient to justify an engineer in speaking of it *in the plural*, and declaring to the people of New Orleans that "jetties" had been tried at the Southwest Pass, and that the system there was a failure.

This statement, made without any qualifying explanation whatever, and reiterated again and again by the advocates of the canal, has served more than any other one erroneous statement to confuse the judgment of your people respecting the jetty system, and to array them in hostility to the only proper method of solving the problem at the mouth of the river.

It is a popular fallacy to imagine that the river comes to rest as soon as it meets the sea. If this were so, a current "passing the outer end of the jetties perpendicular to them" might be of some use. When I proved, before the committee here, by the quotation from Humphreys and Abbott above given, that there did exist currents below the river current in the gulf, "capable of sweeping to one side or the other all deposit," one of your representatives disingenuously strove to avoid the issue by declaring that it was a *littoral* or shore current, which was not to be found. A current of this kind, passing immediately in front of the jetties, would be of no use whatever, for it would only tend to divert the river, as it enters the gulf, in the direction of such current, and cause the deposit to be distributed along immediately beneath the river track. It matters not, however, by what name the current be designated, if it be as Humphreys and Abbott state, "sufficient to transport the material of which the bar is formed."

The bar is erroneously said to be the point of equilibrium, or of

rest, between the gulf and the river, and hence the deposit is supposed to be all dropped there. Gravity causes the river current, while the friction of the river bed causes the resistance. The point of rest is where these opposing elements cease to act. The river will flow quite as freely through a bed of salt water as it will through one of alluvion. When it enters the gulf, although it has no inclination of surface to sustain its current, the momentum it has acquired in its downward course continues to drive it onward. That it does continue to flow onward in the gulf *as a river*, the following extract from Humphreys and Abbott's report (Appendix, page xviii.) clearly proves:

"During a calm day and large discharge, river water can be obtained for many miles outside the bar, on the surface, and to a depth below equal to the mean depth of the bar."

Currents which flow in the gulf *beneath* the river bed are those which most effectually distribute, over a wide area of sea bottom, the deposit which it carries.

If the truth be once impressed on the mind, that the river maintains for some distance a distinctive channel through the gulf, the effect of the feeble tides at the mouth will be more clearly comprehended. These average less than fourteen inches in height, and while they simply act to raise and lower the fluid channel through which the river flows after leaving the land, they really oppose no barrier to its onward progress. The *average* velocity of the current is maintained as though the sea were at rest, the retardation due to the flood tide being compensated by the increased speed induced by the ebb.

Rèvy, in his recent work, "Hydraulics of Great Rivers," (page 22) tells us that if the depth be doubled (the volume and inclination of surface remaining unchanged) the speed will be doubled, and that it will be increased three-fold if the depth be three times as great. As the stream is only enabled to carry the deposit by virtue of its velocity, it must be evident, if the speed be doubled by doubling the depth between the jetties, that it will maintain its momentum through the gulf to more distant and greater depths, and thus the re-forming of a bar in front of the jetties will be indefinitely delayed.

That the current is increased in proportion as the depth is increased, is because the surface of the river bed in contact with the stream is proportionately diminished. The more rapidly it emerges from the jetties, the more distant in the gulf will be the point of equilibrium where the impelling and retarding elements, gravity and friction, cease to act, and where the river comes to rest and is obliterated. Just in proportion as it loses its velocity will it drop its deposit. The heavier portions will be swept to the one side or the

other by the tidal currents passing transversely *under* the river bed in the gulf, while the lighter sediment will fall in its more profound depths.

The amount of solid matter discharged from the Southwest Pass in one year is estimated in Humphreys and Abbott's report as being equal to one mile square and nine feet deep. As the water is two hundred feet deep three miles from the bar, if all this deposit could be concentrated and dropped on one square mile there, and made to form a prism of that base, it would require eighteen years to build it up within twenty feet of the surface.

One of the distinguished agents of your Chamber of Commerce here, Prof. Forshey, tells the Congress of the United States that he has been taught "modesty and humility in the presence of the gigantic torrent," and gives an evidence of his modesty by claiming, in his pamphlet, that he has devoted much more time and personal labor to the investigation of the physics and phenomena of the river "than any other one man living or dead." Whilst your other representative, ex-Governor Hebert, with no less modesty, has informed both committees that he himself graduated at West Point, at the head of his class, in which were the living Sherman and the dead Thomas, and that he thinks it would be very unwise to trust so great a work as this to the crude notions of "*an outsider*."

Had the Governor not graduated at the head of his class and learned at such a tender age all that is worth knowing in this world, he might possibly still acquire some knowledge of engineering and of the Mississippi river by returning to West Point; for he would now be taught facts and principles in his profession there, drawn from the experience of this *outsider*, and would have them explained to him by the writings, diagrams and models which were supplied by him at the particular request of that institution. While this *insider* was displaying such marvelous precocity by beating Sherman and Thomas at school, and the indefatigable Professor was experimenting with a keg with two valves in it, to find out what was going on in the bottom of the river, and was publishing to the world the new discovery that by far the greatest portion of its deposit was pushed along its bed, and that sand was not carried by it in suspension, I was daily learning the falsity of these theories by hard work on the river bottom, in the diving bell, and by removing the sand from the decks and cabin floors and staterooms of wrecked steamers after they were again set afloat by the steam pumps and wrecking boats of Eads & Nelson. Your press reiterates the refrain that all the distinguished engineers of the country denounce the jetties, and favor the canal, whilst I am supposed to know nothing of the Mississippi river and the Southwest Pass, although for thirty-five years I have been most intimately identified with it, and although there is not a stretch of your river fifty miles long, between St. Louis and New Orleans, in

which I have not stood upon the bed of the stream beneath the shelter of the diving bell.

Your people seem to have forgotten that the barque Mary Ellen was wrecked on the bar at the Southwest Pass, and that after fruitless efforts to recover her and her cargo by others, it was by Eads & Nelson's labors, twenty years ago, that the property was saved. The practical knowledge acquired in that work, occupying sixty or ninety days, enables me to speak with much more certainty of the ability of the bar to sustain my proposed works than could be given by any theories founded on assumed conditions which do not exist.

It has been asserted again and again that jetties can not be made to stand at the Southwest Pass, because a pole can be pushed down by the weight of a man eight or ten feet deep in the mud. Many railroads are daily carrying their ponderous trains over ground through which this can be done quite as easily.

You urge that my "jetties will not stand against worms, and will be readily undermined by the current."

The first part of this objection is groundless, because the jetties, when completed, will not be composed of wood. The second part is equally groundless, for you must confess that it is absurd to predict the undermining of the jetties, when you do not know the manner of their proposed construction, nor the methods that will be adopted to prevent their being undermined.

I know just as much of the bar at the Southwest Pass as any advocate of the canal, and I know absolutely that it is capable of holding the jetties I expect to build on it. On page 65 (House Ex. Doc., Second Session, 36th Congress), speaking of Craig & Richtor's dam, Wm. Johnson, supervisor, reports to Col. Long that "over 4,000 feet of the dam is driven in a blue clay bottom with a depth of from 7 to 15 feet, below which an indurated bed of white sand is found with an average thickness of 10 feet." Their dam would have failed even if the bottom had been of the firmest material, simply because it was improperly constructed.

Whether or not in my dealings with men I possess as much modesty as the eminent representatives of your Chamber do, I am sure I have not learned "modesty and humility in the presence of the gigantic torrent." Nor do I believe that it can be controlled by modesty and humility, any more than the furious waves of the German Ocean and its monster tides are kept from devastating half the territory of Holland by such virtues.

I should, however, have a low estimate of the mental power conferred by the Creator upon man, if I did not believe him capable of curbing, controlling and directing the Mississippi according to his pleasure, from the Gulf of Mexico to its most attenuated rivulet. It is a question of money and brains alone. With the little stock of these two indispensable elements which I have had at my command,

I have controlled its currents, improved its harbors and channels, and have rescued many millions from beneath its floods and shifting sands.

Your distinguished Professor, for whom I really entertain great respect, says to the Committees in his pamphlet: "He came before men of judgment to confess his disasters, his failures; and to acknowledge his supreme impotence to make channels, or preserve them when made by the Mississippi River."

We differ. I have no confessions of disasters and failures to make, for in my dealings with the Mississippi I have had none.

To those who in early youth gave such promise, by graduating at the head of their class, having learned everything, and with nought else to do but

"Climb Parnassus by dint o' Greek,"

it doubtless does seem unwise to intrust to *an outsider* the problem of opening any one of the important channels of the country; but to others it would seem like downright folly to anticipate anything but melancholy failures from men who, alluding in eloquent terms to their disasters, frankly confess at the threshold of an undertaking their "supreme impotence." Thus admonished, the country can not expect important results from their efforts, or that their structures will stand in time of need. The learned Professor candidly declares, in his pamphlet, that "whenever the deep abrasions, beyond the reach of the human eye, turned toward his works, he had learned to retire before the dread forces, and place his feeble works beyond the reach of the devourings," etc.

Yet while acknowledging their professional impotence and failures, they would lead Congress and the people to believe they are the shining lights to guide them safely in great technical questions.

The mistaken theories which are advanced by the representatives of your Chamber will constantly insure failures and disasters by those who practice upon them. The laws which guide an engineer are immutable, and never deceive. Failures and disasters in his profession result almost invariably from the non-observance of these laws, or from a want of knowledge of them.

What I know of the Mississippi are facts, and facts are the uncut jewels which grind false theories to powder. With these facts, the arguments and assertions made by your representatives here have been demolished one after another, and they have now incontinently retired behind their earthworks—*the mud lumps*. From this sole remaining stronghold they have just issued the proclamation I herewith inclose, headed "Mud lump blockade." I will leave them there for the present, but when the lumps are in my way to the Gulf I shall blast or dredge them out rapidly, and if I find them rising in the line of my jetties I shall esteem it a piece of good fortune, as they will then constitute part of my proposed works.

Forgetting that I offer to do this work for one-half the cost estimated by the United States Engineer Board, your agents strive to create the idea that the magnitude of the proposed amount is so great as to warp the sincerity of my judgment as an engineer, and piously exclaim in my behalf, "Lead us not into temptation."

Before quoting the Bible so devoutly they should remember that "charity thinketh no evil." How lovely they would appear if they had only combined the "modesty and humility" referred to in their pamphlet with this highest of all virtues, charity!

When reflecting on the interest which paid agents have in prolonging this controversy, regardless of how the nation may suffer, I am tempted to quote the suggestive scriptural exclamation, "Doth the wild ass bray when he hath grass, or loweth the ox over his fodder?"

I have been assailed with the charge that my proposition is made solely in behalf of the railroads which paid for the bridge at St. Louis. Those who assert this silly falsehood know better. The bridge is not owned by railroads. Not one dollar was ever supplied in money, credit, or anyting else in aid of its construction by any railroad in existence, and no road owns a dollar in it. Nor has any railroad or its owners or managers had anything to do with the proposition I have made to the United States.

Those who advance this ridiculous falsehood have been compelled, in trying to give it some color of truth, to ungenerously assail, as enemies of the improvement of the mouth, those who reside in New England and the extreme North, whereas many of these gentlemen view such an improvement in its true and national light, and will support any measure to accomplish it that is agreed upon by those most directly interested.

If the United States grants the privilege I ask, no one else can suffer so severely in any possible event of failure as myself; and no community will be so well repaid as yours when I succeed. I feel the full responsibility of what the people of the Valley of the Mississippi will demand of me if I undertake it; and I feel just as fully sensible of my absolute ability, if my life be spared, to give to the river the deep, unobstructed, and permanent outlet I propose. If I fail, I lose my fortune, the money of my friends, my influence, and my reputation. When such engineers as Barnard, Chanute, Wilson, Flad, Bayley, Smith, and others of the very ablest of the land, declare that the jetty system is the only proper one to be employed, and when I put at stake everything I possess upon the result, it is not only unwise and unjust, but exceedingly ungenerous in you to permit me to be assailed in the manner I have been by the press and citizens of New Orleans.

Many of you have known me personally for more than a quarter of a century, and know, too, what I have already accomplished, and

if professional opinions are to be valued according to the results achieved by men who utter them, I do not know of anything accomplished professionally, by those who predict my failure, that should entitle them to a greater share of your confidence than I myself am entitled to by such standard of value.

This assertion may not evince a modesty equal to that of my two eminent opposers here, but I make no claim to modesty or humility; and if I had a stock of it equal to theirs, I should, in dealing with those in New Orleans who assail me, still cast it all aside, and trust to facts alone to defend myself and to disabuse their minds of error, and, if possible, secure their good opinion. If their unwise opposition is kept up, it may indefinitely delay all improvement at the mouth of the river, for it will call out such arguments against the canal (not from me, but from others) as will effectually kill it forever. If I am permitted to proceed, I shall certainly open the mouth of your river, and will double the value of every foot of ground in your city in two years from the time I commence the work. I am therefore entitled to your earnest encouragement, and while thus declining your request to withdraw my proposition to the Government, I confidently hope this presentation of the reasons for so doing will prove satisfactory to you, and will secure for me your cordial support, as well as that of the people of the whole Valley of the Mississippi.

Very respectfully,

JAMES B. EADS.

REVIEW

OF THE REPORT OF GENERAL HUMPHREYS, CHIEF OF ENGINEERS, U. S. A.

WASHINGTON, May 29, 1874.

Hon. S. A. Hurlbut, U. S. House of Representatives:

DEAR SIR,—I respectfully ask your attention to the following facts connected with House bill No. 2342, reported by you from the Committee on Railroads and Canals.

The consideration of the measure embodied in the above bill was fixed by the House for the 21st of April. On that day a few copies of

Gen. Humphreys' report (Ex. Doc. 220) were received in the House, and delivered to some of the members. As certain statements in it are based upon unsound theories calculated to mislead the judgment of Congress, it is proper to correct them.

General Humphreys makes an elaborate argument, to prove that jetties at the Southwest Pass, to produce 28 feet, will require an annual extension of 1,200 feet. General Newton sustains this view in the same report.

The following extracts will fully explain the foundation upon which their arguments are based:

* * * "The first, the ascertained fact already mentioned, that throughout the whole course of the river there is a mass of earthy matter pushed along the bottom of the river (not suspended in the water) moving at a much slower rate than the current of the river.

* * * * * * *

"The second is the ascertained fact that, where the fresh-water current of the river meets the salt water of the Gulf, the fresh water rises upon it, and creates a dead angle of salt water on the seaward side of the bar; and when the earthy matter pushed along the bottom of the river arrives at this point, the fresh water having risen from it, there is no longer any pushing force to keep the earthy matter in motion. It remains in the still salt water, forming an accretion to the bar." (See page 9, Ex. Doc. 220.)

"'The current in the Southwest Pass is quite equal to pushing this material along the bottom; but when the river water begins to ascend upon the salt water of the Gulf, the rolling material is not carried with it, but is left upon the bottom in the dead angle of salt water. A deposit is thus formed, whose surface is along or near the line upon which the fresh water rises on the salt water as it enters the Gulf. *This action produces the bar.*'" (See Humphreys and Abbot's Report, p. 446.)

"Now, it is obvious that the materials rolled by the currents upon the bottom will be arrested as soon as they reach this dead angle, or space without currents, and that the upper surface of the new bar will be coincident with the slope at which the river waters incline upward." (Gen. Newton, Ex. Doc. 220, page 29.)

To sustain this theory of bar formation and advance, it is absolutely necessary to establish two facts, which are assumed as the basis of the whole theory: First, that on the outer slope of the bar a "dead angle, or space without currents," exists between the river water and the bottom; and second, that the material to form the bar is "pushed" along the bottom.

Humphreys and Abbot say, on page 449 of their report:

"As a velocity of 0.5 of a foot per second is sufficient to transport the material of which the bar is formed, the action of Gulf currents in carrying into deeper water the material *pushed by the river* into the Gulf is evident. [The Italics are mine.]

Hence, if the fact be proven that this angle of salt water is not dead, but is swept by currents exceeding this velocity of half a foot

per second, it must then be evident that the pushed material does not find a "space without currents" on which to rest, and that it can not come to rest as stated.

In Appendix G of Humphreys and Abbot's Report, cxxvi, Professor Forshey, who had been engaged in "Current Measurements at the Southwest Pass," says: "We have a velocity *at the bottom* on the bar, full two miles outside of the land, of two feet per second." The words "at the bottom" are put in Italics by Professor Forshey. The velocity recorded by him is four times as great as that required to keep in motion the material "pushed by the river" along the bottom.

On page cxxix, and following, of same Appendix, we find results of current measurements on the outer slope of the bar in this dead angle, as follows:

Date.	*Depth.*	*Velocity.*
1859, May 12	25 feet	1.05 feet per second.
" " "	40 "	1.22 " " "
" " 14	25 "	1.25 " " "
" " "	40 "	1.18 " " "
" " 16	25 "	3.33 " " "
" " "	40 "	2.22 " " "
" " 20	25 "	1.85 " " "
" " "	40 "	2.00 " " "
" " 26	25 "	1.33 " " "
" " 27	35 "	2.25 " " "
" Sept. 5	22 "	.92 " " "

The average of these observations is nearly 1¾ feet per second, or more than three times the velocity that Humphreys and Abbot tell us is sufficient for "carrying into deeper water the material pushed by the river into the Gulf."

If these quotations be not sufficient to disprove the existence of a space without currents on the outer slope of the bar, the following, from page 449 of Humphreys and Abbot's Report, would be ample to show that this dead angle is continually swept by currents amply sufficient to move the deposits:

"The investigations of the Coast Survey have also shown that the tidal wave approaches the mouths of the Mississippi from a southeasterly direction. With this tidal wave there is near the coast a tidal current, in the same direction. The tidal wave lifts up the river current in the Gulf, and the tidal current passes under it, though checking it to some extent in so doing. The direction of this tidal current is modified by its contact with the river current, and to a greater degree by its contact with the outer slope of the bar deposit. In the case of the Southwest Pass, a flood tide brings a current from the southeast, which is changed to a southwesterly direction, more westerly than that of the river current, by the bar deposit along the eastern side of the mouth of the Pass. The ebb tide is accompanied by a current from the opposite direction, which is similarly diverted by the deposit on the western side of the mouth of the Pass, the direction being more southerly than the current of the

river. Winds may change the direction and force of these currents, which, in mid-river current, at a depth of forty feet, are shown by the observations to vary from three-tenths of a foot to two and five-tenths feet per second."

It only requires common sense, without engineering lore, to see that these conditions are entirely inconsistent with the assumed "dead angle or space without currents."

As a dead angle or space without currents constitutes one of the two conditions absolutely necessary to sustain General Humphreys' argument, it will be seen by this disproof of its existence, from testimony which he can not impeach, that his statement that the bar will advance under the effect of the jetties at the rate of 1,200 feet per annum is utterly without foundation. After thus completely disproving one of these two "facts" on which his argument rests, it is needless to discuss the other, as his position can not be sustained unless both exist.

The bar at the Danube having failed to advance in accordance with "the dead angle" theory, under the influence of the jetties, it is absolutely necessary to show some remarkable difference between that stream and the Mississippi; otherwise this favorite theory, based upon the revelations of Prof. Forshey's keg, and so authoritatively set forth on page 446 of Humphreys and Abbot's report, must be exploded. Accordingly, the reason why the bar *does not* advance at the Danube jetties, and why it *must* advance before those of the Mississippi, is thus stated on page 6, Ex. Doc. 220:

"From the foregoing it is apparent that the Sulina bar of the Danube has no resemblance to the bars at the mouth of the Mississippi River, and that what they have been dealing with in the improvement of the Sulina is a bar or shoal derived chiefly from the deposit of *earthy matter held in suspension*, and not *earthy matter pushed along the bottom of the bed of the Sulina.*"

How does the Chief of Engineers know that little, or none, is pushed along on the Sulina's bed, and that enormous quantities are pushed on the bottom of the Passes of the Mississippi?

The specific gravity of the matter suspended in the Danube is two and a half-times the weight of water, or nearly 28 per cent. heavier than that in the Mississippi. Does it seem reasonable that in the stream in which the sediment is *heaviest* there should be so very little pushed on the bottom, while *enormous quantities* are pushed along the bed of the stream in which it is *lightest*? This statement of the Chief of Engineers is simply an assertion; advaneed not only without proof, but in disregard of the laws of gravity.*

* On page 33, Ex. Doc. 219, the specific gravity of the *matters in suspension* in the Danube is stated to be 2.5; while that of the Mississippi is stated in Humphreys and Abbot's Report, page 148, to be 1.96.

General Humphreys, on page 4 (Ex. Doc. 220), makes the following statements:

"The discharge of the Danube, in flood, is about 333,000 cubic feet per second; in low water, about 111,000 cubic feet per second. The discharge of the Sulina, in high water, is about 24,000 cubic feet per second; in low water, about 8,000 cubic feet per second.

"The South Pass of the Mississippi discharges, in high water, about 83,000 cubic feet per second, and in low water, about 25,000 cubic feet per second, and carries to the sea ten times as much earthy matter as the Sulina branch, almost the same quantity as the Kilia branch, and nearly two-thirds as much as the whole Danube."

These statements create the idea that the sediment in the Mississippi in each pass is much greater than in the Sulina, and hence jetties at our passes will be impracticable. It is proper, therefore, to correct them.

The mean daily discharge of the Danube for ten years is given by Sir Charles Hartley at 207,000 cubic feet per second. The South Pass, as will be seen by the quotation above, discharges about one-third of this amount, say 69,000 cubic feet.

Sir Charles Hartley declares, on page 216 of Trans. of the Inst. of Civil Engineers for 1873, "that *the amount of deposit at the various mouths of the Danube was almost directly in proportion to the volume of water issuing from them.*"

We have shown that *by weight* the Danube's suspended matters are greater; and a foot-note on page 119, Ex. Doc. 220, states that *by volume* they are nearly the same as in the Mississippi.

From these facts it remains for General Humphreys to explain how the South Pass, discharging but *one*-third of the volume of the Danube, can carry to sea *two*-thirds as much sediment.

Again, the Sulina Pass discharges two twenty-sevenths of the entire Danube, or 15,331 feet per second, which is more than one-fifth of the discharge of the South Pass; therefore the South Pass *cannot* carry to sea "*ten times*" as much sediment as the Sulina.

These statements simply create doubt in the minds of those not familiar with the subject by conveying the idea that the Danube is comparatively a clear stream, when in reality its waters are charged with an equal volume of sediment, and heavier in character than that of the Mississippi. The quantity of sediment of each outlet depends upon the quantity of water issuing from that particular outlet in either river, and such statements have a bearing only upon the *cost* of the jetties needed at either pass, and not upon their practicability. Sir Charles Hartley's argumsnt, in favor of the Sulina Pass, was simply that the smaller pass involved less expense because its bar was less distant from land, and there being a less amount of water issuing from it, the works needed to control the stream would be less costly. General Humphreys recognizes this fact when he declares that jetties for the South Pass will cost $4,150,000, and an annual cost

of $670,000 for maintenance, or the equivalent of an investment of $15,250,000, while those at the Southwest Pass he estimates as equal to an investment of $23,000,000.

By the terms of my proposal, I am cut off from using the South Pass, as it is too narrow.

The jetties at the mouth of the Rhone are referred to on page 29 of the report, as follows, evidently with the intention of weakening confidence in the proposed jetties:

"The disappointment suffered from the application of the jetty system led to the construction of a lateral canal connecting the Rhone with the Gulf of Foz, and having a depth of 23 feet."

Sir Charles Hartley stated to me in person, that in case this work at the mouth of the Mississippi is undertaken, it will be important to extend the jetties at once with all speed to the deep water, to lessen the cost, as the bar would advance more rapidly until this shall have been accomplished. This is the opinion of several other distinguished engineers, who do not believe any rapid advance of the bar will occur afterwards. In view of this evident fact, the following from page 29 (Ex. Doc. 220), may serve to show why jetties at the Rhone did not succeed:

"Upon the Rhone, when the jetties were completed, in 1852, the bar was about seven-eighths of a mile in advance; in 1863 this advance was nearly one and three-fourth miles; the progress during this interval having been three times the ordinary rate."

If the bar was seven-eighths of a mile in advance of the jetties when they were completed, this fact should suffice to explain the cause of the disappointment. The fact is attested by Humphreys and Abbott, in their report, which bears date 1861, in foot-notes on pages 452 and 455, that these jetties effected the desired increase of depth. They were therefore of value for seven or eight years, although not built out to the bar.

Another statement in this report deserves notice. General Newton declares, on page 34:

"The rapid extension of a pass by jetties, though under all circumstances prejudicial to the discharge through it, would not be so soon felt in its consequences in the ordinary river; but at the Mississippi delta, such an operation might inure to the rapid deterioration or ruin of the pass, and this is the reason why the application of the jetty system to these mouths must sooner or later wear them out by forcing the waters into other channels."

Sir Charles A. Hartley, in direct opposition to General Newton, declares, on page 217, Reports Institute of Civil Engineers, 1873, that the absence of training works or jetties at a pass, where the flow is increased, tends to the injury or shoaling of the pass, while jetties tend to increase the flow into the pass, and consequently to deepen it.

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Of all arguments yet advanced against the jetties, this certainly is one of the weakest and most indefensible. If it could possibly occur that the jetties obstructed the pass by being wrecked and carried away, as some have thought possible, and lodged on the bar, General Newton has himself supplied the proof that such casualty could not result in injury, for he says (1st paragraph, page 34):

"The same reasoning applies to the passes, which, perforated through the most yielding alluvions, will always suffice to discharge the river, and should one by some obstruction be impeded in its discharge, the others enlarge their cross-sections to supply the emergency."

We learn, on page 6 (Ex. Doc. 220), * * * "even at the mouth of the smallest pass the quantity of both kinds of deposit matter is enormous."

Prof. Forshey has assured the committee that the amount *pushed* on the *bottom* of the Mississippi, was fifty times as much as that carried by it in suspension. And the Chief of Engineers, by declaring the quantity of *both* kinds of matter to be enormous, leads his readers to believe there is but little difference in the quantity of either. On page 149 of Humphreys and Abbott's report, the estimated quantities are stated as equal to 1 square mile 27 feet deep of *pushed* material, and 1 square mile 241 feet deep of *suspended* matters; the quantity supposed to be *pushed* being about *one-tenth* of the whole.

On page 149 of Humphreys and Abbott's report, the means employed to make the discovery that this enormous amount of matter is being pushed on the bottom is thus described:

"A keg similar to that used in collecting water below the surface, was sunk to the bottom of the river. The current immediately overturned it, and the valves opening allowed the water to pass freely through. After remaining a few minutes it was drawn suddenly up, and was invariably found to contain material such as gravel, sand and earthy matter."

Prof. Forshey has informed us that no investigations or experiments with a keg, or by any other means, were ever made by Humphreys and Abbott, to determine this question, and that the principal hydrometrical data in Humphreys and Abbott's report were supplied by himself. To him belongs the honor of discovering, by means of the keg described by Humphreys and Abbott, the enormous amount of material pushed on the bottom, and "of which the bar is formed;" therefore, upon his investigations mainly rest the fabric of arguments and conclusions respecting the bar advance, published by Generals Humphreys and Newton.

On page 5, the Chief of Engineers says:

"Now the earthy matter held in suspension by the Mississippi river is mainly kept in suspension by the horizontal and vertical irregularities of the bed (see page 139, Report on Mississippi River), which con-

stantly stir it up so long as these irregularities exist. When these vertical and horizontal irregularities diminish, the quantity of suspended matter diminishes, some of it falling to the bottom; and when these irregularities cease altogether, the greater part of the suspended earthy matter begins to fall to the bottom."

This is not the place to prove the fallacy of this statement, although I cannot let so grave an error in physical science go forth from such distinguished authority without protest. It is a necessary sequence, however, to the assertion that there exists no relation between velocity and quantity of sediment in suspension. If velocity be not the cause of suspending it, some other reason had to be given; and Gen. Humphreys has stated one in direct conflict with every-day facts observed in aqueducts and canals devoid of these irregularities. In India, where canals are located through alluvial districts, and are supplied with water holding sedimentary matters, it becomes necessary that a current be created sufficient to keep them from depositing, while to prevent scour, the current must be limited strictly to such velocity.

Sediment is unquestionably taken up and kept in suspension by the upward motions imparted to water by the series of curves which its atoms are continually making while flowing over its bed. These curves are created by the smoothest beds, and result from the friction of the water in contact with the bottom. Hence, no bed of a stream can be so smooth as to prevent the suspension of loose or disintegrated particles of sand and earthy matters when sufficient velocity of current is attained. As the rapidity of the stream increases it is enabled to suspend larger particles, and even gravel may be raised some distance from the bottom.

Frequently in the upper part of the river, in low water, the current cuts tortuous channels down many feet lower than the dry surfaces of the sand-bars. By the floods these channels are quickly obliterated and filled up when they cross the main current of the full river. During one of these floods I had occasion to descend to the bottom in a current so swift as to require extraordinary means to sink the bell; and although the sand was apparently drifting like a dense snowstorm at the bottom, sixty-five feet below the surface, and was doubtless being swept off of bars that were dry in low water, I feel confident it was really afloat or suspended. This was near Island No. 10, and in a current much more rapid than any that sweeps by New Orleans. My boat was carried away the next day by the drift-wood; and this constitutes my only experience on the river bottom in *flood-time.* Frequent examination of the bottom at ordinary stages of water enables me to declare that sand and other sedimentary matters are carried in suspension, and not *pushed* along the bottom. Drift-wood, balls of clay, or other aggregations of earthy matter are doubtless rolled or *pushed* along on the bed, and sometimes gravel and bould-

ers, but the amount of these passing New Orleans is very small. That which was once the largest item, viz., sunken drift-wood, is yearly diminishing, as the clearing of the lands bordering the river increases

On page 5, Ex. Doc. 220, General Humpreys states: "In the vicinity of New Orleans the material thus dropped, which is drifting along the bottom, is the same kind of material as the sediment held in suspension, no coarse material being carried or pushed by the river past this point."

This is simply assertion without proof. Sand, which is the heaviest material carried, is found in the river at all depths from the surface to the bottom.

Gen. Humphreys says, on page 5, that "the horizontal and vertical irregularities of the bed cease almost entirely, where the Southwest Pass begins to widen 7.3 miles from the crest of the bar." Yet, without these irregularities of the bed, we find the water capable of sustaining sand near the surface on the bar, as is shown by the following, from Humphreys & Abbot's report (Appendix A, page xviii.)

"Experiments were made on the nature and quantity of the sand, by sinking a closed box, pierced on opposite sides with holes of unequal diameter, the larger orifices being placed up stream. The water, in passing through, had its velocity diminished, and deposited the coarser particles held in suspension. In this manner the sand of the bottom and surface currents was obtained in different parts of the delta. The sand of the bottom is a little coarser than that from the surface."

In sinking the large caissons of the bridge at St. Louis, they were suspended like huge diving bells near the river bottom, for several days before they finally sank into and entered it. They were illuminated, and I was repeatedly in them, and if any such pushing process had been going on there, I would have discovered it. Five miles below Cairo, I searched the river bottom for the wreck of the "Neptune," for more than sixty days, in a distance of three miles, without finding any material pushed along the bottom. My boat was held by a long anchor line, and was swung from side to side of the channel, over a distance of 500 feet, by side anchor lines, while I walked on the river bottom, under the bell, across the channel. The boat was then dropped twenty feet further down stream, and I then walked back again as she was hauled towards the other shore. In this way I walked on the bottom four hours at least, every day (Sundays excepted) during that time. The bottom there is of gravel, cemented into large masses with oxide of iron and earthy matters; and if any material had been *pushed* along the bottom it could not have escaped my observation. There was none even *drifting* on the bottom there. At Plumb Point, 100 miles below, I had even a still more protracted search in the same manner, for the "America." Besides these, I have been on the river bottom on not less than five

or six hundred other localities, and I know that no such material as forms the bars of the passes is *pushed* on the bottom of the river in any such quantity as is requisite to form them, or to serve as a basis for the calculations of bar advance under the influence of the jetties, as made by Gens. Humphreys and Newton. Nor is it necessary to create any such special theory of bar formation for the Mississippi River. The bars at its mouth are not formed by any process of nature which differs materially from that at the mouths of the Ganges, the Nile, the Danube, or any other delta river in the world.

The whole question really at issue in this matter, is whether the jetties will require to be advanced 1,200 feet per annum, as Gen. Humphreys declares, or whether they will not. That *it is practicable to build and maintain them*, and *that they will produce the required depth*, Gen. Humphreys has, I think, never publicly denied. On the contrary, he has declared on page 455 of Humphreys and Abbot's report, that they *are* correct in theory. On page 455 of the same report is a recital of the recommendations of the Board of 1852, which recommended the trial by jetties, *and only recommended the canal after all other means should fail.*

Gen. Humphreys, in the following passages which I have put in italics, evidently concedes the fact, that the jetties will produce the desired depth. On pages 7 and 8 of his latest report (Ex. Doc. 220) he says:

"If we refer to the channel where it is 25 feet deep we find the width to be about 4,000 feet; and the mass of the annual addition to the bar being the same, the annual extension on a front of 4,000 feet, instead of being 338 feet, will be about 1,000 feet, and this will be about the annual extension of the bar for a depth of 25 feet if the jetties are suitably arranged for that depth. If they are at a greater distance apart, the depth will be less than 25 feet. If they be a less distance apart, the depth will be greater, and, the addition to the bar being formed on a less front than 4,000 feet, will have a greater annual extension than the bar formed on that front. *So that in applying jetties to permanently deepening the bar of the Southwest Pass to 25 feet, we must expect an annual extension of the bar of about* 1,000 *feet.*

"If the depth to be maintained is 27 feet at low water, or 28 feet at high water, it will be found by a similar process that the annual advance will not be less than 1,200 feet.

"*The jetties may be so arranged as to cause a greater depth than the one required, and thus obviate for a time the necessity of their annual extension into the gulf*, but such an arrangement will entail a proportionately greater first cost in their construction. The final result as to cost and depth will be the same whether the jetties be converging or parallel, and the parallel has therefore been assumed as the model in this discussion."

I think no one can doubt, after reading these extracts, that Gen. Humphreys *knows* that the jetties will produce the depth. The only argument made against them is their greater cost, and the necessity of an annual extension of 1200 feet per annum. The objection as to cost falls to the ground under my proposition, and all that remains is

the question: *will the required extension of the jetties be twelve hundred feet per annum*, or any lesser rate of importance? Gen. Humphreys answers this question in the affirmative. The views expressed in Ex. Doc. 220, by Gen. Barnard, and those of Col. W. Milnor Roberts, Gen. J. H. Wilson, Col. Shaler Smith, and Messrs. Chanute, Bayley, Flad, Corthell and others, expressed to me personally, sustain my faith in the negative; for the United States does not contain engineers more able than this list presents. Admit, however, that such advance will be necessary, and that it will cost all that Gen. Humphreys estimates (one million dollars per annum), the government retains an ample amount of my compension to insure such extension, and it will enjoy a deep river until a canal, or better remedy, if needed, is provided. If I fail entirely, I and my associates lose *our* money, and the country is no worse off. It does not lose a dollar, nor are the military engineers delayed in perfecting their canal plans. If, however, the eminent engineers who do not believe such rapid advance of the jetties will he needed, are correct, and the jetties succeed, the nation secures an inestimable prize, AN OPEN MOUTH RIVER. With so much to gain, and so little to lose in accepting my proposition, can it be deemed wise to decline it? If Congress refuses to let me demonstrate the problem at the sole risk of myself and associates, the valley must wait in patience for relief.

I beg before closing to correct and comment upon a misstatement made by the Chief of Engineers, which does me injustice personally.

Gen. Humphreys declares on page 10, of the report:

"It has been recently stated by a civil engineer, in a pamphlet concerning the improvement of the mouths of the Mississippi River by jetties, that the amount of sedimentary matter carried in suspension by the Mississippi River is in exact proportion to the velocity of its current; and that as a given velocity of current will keep in suspension a corresponding quantity of solid matter, at a less velocity a certain portion of it will be dropped. To illustrate this he states that—

"'When the Bonnet Carre crevasse occurred, the river below it (107 feet in depth) was shoaled up 31 feet, because the volume of water in the river, being lessened by the crevasse, was no longer sufficient to maintain the normal current in a channel large enough to carry the entire river; consequently the current below the crevasse slackened, and the excess of load was dropped in the channel until the bottom was filled up 31 feet with the deposit. This reduction of channel was sufficient to re-establish the current and prevent further deposit.'"

This *verbatim* quotation from my letter to Senator Windom, respecting the crevasse, fixes this statement of a "civil engineer" upon me. My real proposition, on the first page, in that letter, is thus stated: "The amount of this matter, and the size and weight of the particles which the stream is enabled to hold up and carry forward, depend wholly upon the rapidity of the stream, modified, however, by its depth."

As this proposition is much more brief than the *verbatim* quotation by which this *mutilated* statement of "a civil engineer" is fixed upon me by Gen. Humphreys, it is to be regretted that my real proposition was not likewise given in my own language. By leaving out the words "*modified, however, by its depth*," I am made to appear as ridiculous as though I had asserted that the capacity of the river bed is in exact ratio to its width, *without reference to its depth*. The arguments and tables of velocities of current and quantities of sediment, with which on pages 10, 11 and 12 he demolishes the mutilated proposition he has fastened upon me, show that the misapprehension of my actual statement has cost the Chief of Engineers much time and labor to refute WHAT I NEVER ASSERTED.

General Humphreys continues on page 10 with the following:

"The first statement is in direct conflict with the results of the long-continued measurements made upon the quantity of earthy matter held in suspension by the Mississippi River at Carrollton, near New Orleans, and at Columbus, twenty miles below the mouth of the Ohio, one of the chief objects of which was to determine this very question, whether any relation existed between the velocity and quantity of earthy matter held in suspension. These results prove that the greatest velocity does not correspond to the greatest quantity of earthy matter held in suspension. On the contrary, at the time of the greatest velocity of the current at Carrollton the river held in suspension but little more sediment per cubic foot than when the velocity was least. When the quantity of earthy matter held in suspension was greatest, the velocity was two feet per second less than the greatest velocity, the quantity of earthy matter in the one case being three times as great as in the other. We find at another time, when the velocity was one-half the greatest velocity, the quantity of earthy matter held in suspension was double in amount."

These remarks are intended to controvert my real statement, and therefore, if they prove anything, it is that no relation exists between the rate of current and the quantity of load suspended; for he says one of the chief objects "was to determine this very question, whether any relation existed between the velocity and quantity of earthy matter held in suspension."

Those who are familiar with the best writers on this subject, know that the ability of the stream to suspend its sediment is believed to be *inversely as the depth*. It is a most notable fact, however, that Humphreys and Abbot did not take into account the element of depth in coming to the conclusion, that no relation exists between the velocity and the load suspended. This will be seen by referring to their report (page 139), and in the above extract, General Humphreys repeats this statement, which he endeavors to prove by deductions drawn wholly from observations upon the velocity of the stream, and amount of its load, but entirely omitting one of the important elements in the problem, viz: the variations in the *depth* of the stream.

The most accurately-prepared table of diameters and capacities of

a lot of different-sized tubs of various depths would indicate no relation whatever between diameter and capacity, if the element of *depth* were ignored. General Humphreys, by leaving out of my proposition this important element, has made me appear as ridiculous as though I had asserted that the capacity of a tub was in exact ratio to its diameter, regardless of depth. His deductions are as absurd as if he were to assert that no relations existed between the diameters of these tubs and their capacities. The absent element in the problem would establish the relation which every one knows must exist between diameter and capacity.

He is welcome to such conclusions as he may draw from pondering over *a part* of the elements of a problem, but I must protest against being published as the author of the mutilated proposition which he has been laboring to disprove.

Gen. Humphreys says on page 12:

"This statement concerning a deposit being formed below the Bonnet Carre crevasse was made just before the survey of the Mississippi delta was begun, and was carefully investigated in the course of that survey. The subject had an important bearing upon the question of using outlets to reduce the floods. It was found there had been no deposit whatever below the Bonnet Carre crevasse, and that the bottom of the river there was composed of hard blue clay, of older formation than alluvion, and that the cross-section had unquestionably remained unchanged."

I am not familiar enough with the facts at Bonnet Carre to dispute the statements of the Chief of Engineers, but I am not prepared to accept the explanation that the difference of thirty or thirty-five feet in depth above and below the crevasse was due to a stratum or bar of "hard blue clay of older formation" below the crevasse, and not to a deposit resulting from the depletion of the river by that outlet; especially in the admitted absence of soundings to prove that the shoal existed *before* the crevasse.

Undoubtedly at one time the bars at the mouth of the river were located miles above the present delta, yet the river has scoured through the various strata of blue clay and sand on which the ancient bars rested, and now sweeps through a channel more than one hundred feet below the highest of the blue clay deposits, and these must have been as difficult to scour through as the one at Bonnet Carre. The sounding lead can not give reliable evidence of the character of the bed of the river, if there be any such amount of material *pushed* along the bottom as General Humphreys claims.

If the facts be precisely as stated—viz., that the diminished depth of the river below the crevasse existed prior to the crevasse itself, it does not at all conflict with the theory advanced in my letter to Senator Windom. The river being already sufficiently diminished in section, there would be no loss of current, and hence no sediment deposited.

The difference in the character of the bed and banks of the Mississippi at different localities must, of course, exert a modifying influence upon the evidence of relation between velocity of current and matter transported. But nothing can be more certain than that, if the current ceased altogether, the load of sediment would drop; and that if the current was restored, the load would again be taken up. The current must therefore be *the cause*, and the suspension of the load *the effect*. If it be the cause, it *must* have relation to the measure or *quantity* of the *effect;* hence, to declare that no relation exists "between the velocity and quantity of earthy matter held in suspension," is to assert that no relation exists between cause and effect. I think, with General Humphreys, that "it is unnecessary to pursue this subject further."

The theory set forth in my letter to Senator Windom, and which Gen. Humphreys has misquoted and endeavored to disprove, met the unqualified approval of many of the ablest scientists of America before it was published. I claim no originality in it, except in applying it to solve the phenomena of the Mississippi River. It gives a simple explanation of the important part performed by the River in the creation and extension of the banks and bars at the Passes. It conflicts with no ascertained fact whatever, and explains every phenomenon presented by the river throughout its delta. On the other hand, the conclusion of Gen. Humphreys, that no relation exists between the velocity of current and the quantity of suspended sediment, is based on a physical impossibility. It necessitates a doubtful bar of blue clay of older formation to explain away one of the truths which conflict with it; while another stubborn fact has to be accounted for by the incorrect theory of "the horizontal and vertical irregularities of the bed." Then, to get rid of the sediment, which in accordance with this theory is supposed to fall to the bottom, when these irregularities cease below New Orleans, and which if suffered to remain and accumulate in the river bed would finally fill it up, it becomes necessary to introduce another peculiar conception, the *pushing* theory, by which the river is supposed to push this enormous quantity of sedimentary matter along its bed and up over the crest of the bar, as a sailor pushes to the scuppers the dirty water on a ship's deck with his squilgee. Finally, after this enormous amount of sedimentary matter is *pushed up* and *rolled over* the oozy crest of the bar, it becomes necessary to create the grandest novelty of all, the "dead angle," or, as Gen. Newton expresses it, "this space without currents" which is supposed to underlie the immediate outflow of a mighty river!

Tyndall has written an interesting essay upon the scientific uses of the imagination, yet he never dreamed of the field of romance opened up by Professor Forshey and his marvelous keg. The scenes

explored by Aladdin and his wonderful lamp possess no such scientific interest as will forever attach to that mysterious region of quiet repose termed "the dead angle." There, secure from the incessant action of the river current, the tireless movements of the tides, and the searching influence of storm waves, we are told, the pushed material which has rolled over the oozy surface of the bar without getting mired down will build itself curiously up and out into the sea in the form of a submerged railway embankment of the exact width of the jetties. We learn that *here* in "this still salt water" this embankment can not be worn down by the action of waves or tides; but, regardless of the ever-increasing depths, will constantly advance 1,200 feet per annum.

That this submarine levee which is to grow out from the jetties can not be beaten down by the waves of the Gulf will never be doubted after examining the following statement of the force which the Mississippi levees are constantly resisting. It will be found on page 108, in the learned Professor's pamphlet entitled "The Delta of the Mississippi." Speaking of the enormous force which the waves of passing steamers hurl against these levees, Professor Forshey says:

> "Thus the violence done to the banks and levees by one trip of the 'James Howard' is measured by 4,600,000 lbs.$\times$14.6$\times$1760, for each mile of her travel. The aggregate force, then, that is abnormal, applied by this steamer, amounts, in foot pounds, to 118,201,600,000 lbs.=60,000,000 tons, or 3,940,000 horse power.
>
> "These quantities are so enormous as to be unappreciable to the mind unless illustrated by some familiar example:
>
> "A levee of nine feet in height, by our recent formula, say that of Humphreys and Abbot, with slopes of two and three to one, contains 1,200 cubic yards in every hundred feet, and 3,000 lbs. to the cubic yard. Three hundred feet of levee, equal to the length of the 'James Howard,' would weigh 10,800,000 lbs., and *the force thrown against the levee or bank, each trip*, by the passing boat, would be $\frac{68160000}{2}$ =34,080,000 lbs.; *more than three times the weight of the whole levee!*
>
> "Thanks to the tenacity of the soils and materials of the banks of the river, these banks *do* stand these forces, repeated fifty times a day under many modified forms; and still they stand almost miraculously this fearful servitude."

The Chief of Engineers has demonstrated, on pages 10, 11, and 12 (Ex. Doc. 220), that no relation exists between *cause* and *effect*. Professor Forshey confirms this; for he proves that the *effect* actually does in some cases greatly exceed the *cause*. He makes it as plain as the dead angle, that the *cause*, which is a pair of steam engines of about 2,000 horse power, can in one mile of the boat's travel produce an *effect* against a mile of Mississippi levees equal to the power of 3,940,000 horses. Elsewere I have referred to the curious statement of the Chief of Engineers, that the *heavy* sediment of the Danube is carried in suspension, but that the *light* sediment of the

Mississippi is pushed on the bottom; and, in the above extract, we see that the force of gravity, just as wonderfully, enables these Mississippi embankments to resist a horizontal force more *three times as great as their weight!*

Before dismissing this interesting subject, it might be well to suggest that the threatened bar advance in front of the jetties may be prevented altogether by employing one of Professor Forshey's 3,940,000 horse-power steamers. This force, judiciously directed into "the dead angle," would certainly enliven the still salt water supposed to exist there, and thus enable it to transport the material of which the bar is formed, into the deep water of the Gulf.

Your obedient servant,

JAS. B. EADS, *C. E.*

POSTSCRIPT.—A paper criticising my letters to Senator Windom, and to The Business Men of New Orleans, signed by a Mr. McMath, civil engineer, only deserves to be noticed here, because of the factitious importance given to it by its distribution in manuscript to members of Congress by the Chief of Engineers. Its arguments being based upon the dead angle theory, are refuted in this letter. It therefore requires no further mention.

JETTY SYSTEM EXPLAINED.

PHENOMENA OF THE MISSISSIPPI RIVER.

The Mississippi is simply a transporter of solid matter to the sea. This consists chiefly of sand and alluvion, which is held in suspension by the mechanical effect of the current. A small portion, consisting of larger aggregations, such as gravel, boulders, small lumps of clay, and drift-wood, is rolled forward along the bottom. By far the greatest portion is, however, transported in suspension. The amount of this matter, and the size and weight of the particles which the stream is enabled to hold up and carry forward, depends wholly upon the rapidity of the stream, modified, however, by its depth. The banks and bottom being chiefly sand and alluvion, are easily disintegrated by the movement of the water; hence the amount of load

lost by any slacking of the current at one place, will be quickly recovered in the first place below where the current is again increased.

The popular theory advanced in many standard works on hydraulics, to-wit: that the erosion of the banks and bottom of streams like the Mississippi, is due to the *friction* or *impingement* of the current against them, has served to embarrass the solution of the very simple phenomena presented in the formation of the delta of the Mississippi, because it does not explain why it is that under certain conditions of the water it may develop with a gentle current, an abrading power, which, under other conditions, a great velocity cannot exert at all. A certain velocity gives to the stream the ability of holding in suspension a proportionate quantity of solid matter; and when it is thus charged it can sustain no more, and hence will carry off no more, and therefore cannot then wear away its bottom or banks, no matter how directly the current may impinge against them.

CAUSE OF CAVING BANKS.

In the upper portions of the delta (which, according to some writers, extends a few miles above Cairo), the width of the river is very irregular. When a rise occurs the current is increased in the narrow parts of the river, and the carrying capacity of the stream consequently becomes greater, and it at once takes up an additional load. When, however, as the stream flows on, it enters a wide expanse, the current is slacked and the excess of load is dropped to the bottom, and thus shoals or bars are formed. From such expansion of channel way, the volume of water thus relieved of a portion of its load, passes into another one of the narrow parts of the channel, and here its current by contraction is again accelerated, and the increased load which it can carry is immediately scoured up from the bottom and sides of the channel. In the bends the centrifugal force of the water makes the current more rapid on the concave bank of the stream, and there it usually gets its additional load, and the caving in of the bend testifies to the rapacity of the water at that point of its course. Once loaded, however, it can carry no more, and hence it may sweep around half a score of other bends below, with equal velocity, without injury to them. If it encounter another expanse, however, it again loses part of its velocity, and with it part of its load, to be recovered again in the narrower parts of its channel below. It is evident, therefore, that if the channel were at all uniform in size, the current would be more constant, and the alternate depositing and recovery of part of the burden of the stream would be prevented. This loading and unloading is synonymous with caving banks and sand-bars.

The lower part of the river, nearly all the way from Red River to the mouths of the passes, is remarkably uniform in width, and is,

therefore, comparatively free from falling banks and shoals. This part of the river is transporting its load with great regularity, and without interruption, to the sea; whilst that above, owing to the alternating contractions and expansions in its channel, transports its burden with great irregularity, dropping a part here and taking up a part there, and thus by successive stages, from season to season, it is borne forward.

If the volume of water were constant, it is plain that the river would soon have a current of great regularity; because the deposit dropped in a wide part of the river, lessens the capacity of the channel there by shoaling it, and re-establishes the proper velocity of current, and thus stops further deposit at that place; whilst at the contracted channel the scour soon enlarges the passage, and consequently reduces the current, and thus further scour ceases at that point.

In a channel of uniform width, when the river falls, the stream occupies only the narrower parts of it, and if these be still too great to maintain sufficient current to transport the load, the excess is deposited in the channel, which is thus further diminished until the current is thereby accelerated to the proper rapidity, after which it ceases to deposit any more.

We see, therefore, that the causes which control the speed of the stream, and those which give to it the ability to hold its burden of solid matter in suspense, are constantly acting in opposition to each other, and thus the equilibrium between them is restored as often as it is disturbed by alternations in volume, or by irregularities in channel.

We not only learn from this how simple some of the most apparently mysterious phenomena of the river really are, but also how futile it would be to attempt either to enlarge or diminish the normal size of its channel anywhere within its alluvial bed. As rapidly as the engineer strives to deepen it without proportionately contracting it, and thus enlarges it beyond the capacity which these natural forces give it, just so rapidly will the current be slacked by the enlargement and the deposit dropped there, and thus lessen it again. And as fast as he may contract it, just so fast will the current be increased, and the consequent scour enlarge it again by deepening it. The *magnitude* of the channel is determined by forces which it is neither necessary nor profitable for the engineer to encounter. The *form* of the channel he can control and alter. If he widen it, these forces will inevitably shoal it; if he contract it, they will just as certainly deepen it.

FRICTION OF BED.

The chief cause which retards the flow of the stream is friction of its bed. As rivers increase in size, the volume of water increases faster than the frictional surface—as the area of a circle increases more rapidly than the circumference, when we increase its diameter. Hence, large rivers invariably flow more rapidly with the same fall than small ones. This explains why the shore current of the river is less rapid than the central current—the latter having less friction in proportion to its volume, the gravity of water in the deep part meets with less resistance and flows faster.

HOW THE PASSES ARE FORMED.

The phenomena presented by the protrusion of the passes of the river out into the Gulf, are equally as simple as those of the river above. A glance at the map shows how remarkably uniform is the width of each of them from their commencement until they reach the neigborhood of the Gulf. In the passes and in the river, for several hundred miles above, the slower shore currents have dropped their excess of load, until the shores have been built up and narrowed in to such a degree, that all further deposits on them tend to increase the steepness of the banks; hence the additional deposit slides down towards the middle of the channel bed as fast as it is dropped. The onward motion of the stream tends to continually draw in its waters from the shore (which is evidenced by the drift-wood flowing always in the middle of the channel of the stream); hence the water, after depositing part of its load near the shore, is again made capable of carrying it by the increase of its velocity, when it again gets near the middle of the stream, and thus the central mass of water is continually made capable of taking up from the bottom, the excess of load dropped by the shore currents. At the mouth of the pass, the angle of rest of the deposit, or the natural slope, is not yet attained. Here the shore currents are continually dropping the surplus load which their diminished velocity is unable to hold up, and thus the shores of the pass are being constantly built up in the Gulf, and narrowed in and brought to the surface of the water, where, with reed grass, marine plants, etc., they are gradually converted into dry land.

THE RIVER NOT SUDDENLY CHECKED BY THE GULF.

It is a popular fallacy to imagine that the Gulf presents a barrier to the onward flew of the stream at the mouth of the pass. On reflection,

it must seem reasonable that a river should flow with less friction between walls of water than between walls of earth. At the bar, the river has its banks of earth no longer, but it still flows between banks of salt water, and over a bottom of brine instead of mud. It has no longer a descent of a few inches to the mile, however, and hence must maintain its current in the Gulf simply by momentum. Friction on its sides and bottom finally brings it to rest; but while its momentum lasts, the widening out into the sea and the final obliteration of the river will proceed very gradually.

That a stream will preserve its individuality for a great distance, while flowing through the sea or through another body of water, can be proven by every river which enters the ocean with a strong and consequently deep volume. The upper Mississippi preserves its identity for a score of miles after having entered the grand channel of the main river, and the dividing line which separates its clear waters from those of its more powerful neighbor can be distinctly traced, in flood time, far below St. Louis. The Southwest Pass current in flood time, can be detected twenty-five miles from the land.*

THE TIDES NO DISADVANTAGE.

If the truth be once impressed on the mind that the river maintains, for some distance, a distinctive channel through the gulf, the effect of the feeble tides at the mouth will be more clearly comprehended. These average less than fourteen inches in height, and while they simply act to raise and lower the fluid channel through which the river flows after leaving the land, they really oppose no barrier to its onward progress. The average velocity of the current is maintained; the retardation due to the flood tide being compensated by the increased speed induced by the ebb.

IMPROVEMENT BY JETTIES.

Jetties are simply *dykes* or *levees under water*, and are intended to act as banks to the river, to prevent its expanding and diffusing itself as it enters the sea.

It is a notable fact that where the banks of a river extend boldly out into the sea, no bar is formed at the entrance. It is where the

* During a calm day and large discharge, river water can be obtained for many miles outside the bar, on the surface, and to a depth below equal to the mean depth of the bar. (Humphreys and Abbott, Physics and Hydraulics of the Mississippi River. Appendix, page 18.)

banks or *fauces terræ* (jaws of earth) are absent, as is the case in delta forming rivers, that the bar is an invariable feature.

The bar results from the diffusion of the stream, as it spreads out fanlike in entering the sea. The diffusion of the river being the cause, the remedy manifestly lies in contracting it, or in preventing the diffusion.

A glance at the accompanying map of the Southwest Pass reveals the narrow and uniform width of the Pass, until it is within about seven and one-third miles of the bar, which is about three miles beyond the land's end. In this seven and one-third miles, the river is building up and extending its own banks into the sea, at the rate of 8 or 9 inches per day. After this seven and one-third miles, its work is finished. *Its jetties* are completed by its own forces, and will probably never change their location, although every time the stream overflows them, fresh deposit will raise them still higher. It is, therefore, evident that the river itself is continually employing the jetty system, and that nature makes parallel, and not converging jetties.

WHY THE BAR WILL NOT ADVANCE IF JETTIES ARE CONSTRUCTED.

The surveys of Talcott 40 years ago, and those recently made by the Coast Survey, confirm what the reader would naturally infer, viz: that as the river builds up and finishes its jetties the bar travels seaward; that the bar moves out not as the cause, but as the effect of the jetty building of the river. Seven and one-third miles above the bar the natural jetties are finished and narrowed to their normal width of 1,250 feet, and there the pass is 60 feet deep in consequence. The bar was once unquestionably where this depth of 60 feet now exists. From this point the river gradually widens out to the sea, like a fish's tail, and the current gradually diminishes from four and one-third feet to about three feet per second, at the bar, and to zero some twenty miles beyond in the gulf.

Since the white man has known the river, this distance between the bar and the narrow and completed banks of the pass above has been the same, viz: Seven and one-third miles. For eleven miles above, the pass presents the same narrow and deep characteristics. The bar has marshalled the way through ages past to the gulf, and the natural jetties have been built up at exactly the same rate of speed, and have constantly kept the bar seven and one-third miles in advance.

It is evident that, as the natural jetties advance, the bar is slowly eroded away. The up-stream part of the bar is gradually cut out and deposited further out in the gulf. A little reflection will show that there must be some strange connection or influence existing between

the finished part of these jetties and the bar, that the distance between them should remain so constantly the same. Evidently the volume and current passing out between the finished jetties or banks where they are 1,250 feet wide, are so great that the bar can not form any *nearer* than seven and one-third miles distant; and it is just as evident that this volume and current are not sufficient to make the bar form at a greater distance.

Now, suppose that by artificial means these natural jetties could be suddenly extended seven and one-third miles out to the bar. The volume of water would be almost, if not exactly the same, and so would be the current. Instead of passing over the bar as it now does, at three feet per second, it would pass out from between these artificial jetties at the rate of over four feet per second. This artificial and parallel construction would give the stream at the present bar the width, depth, velocity and volume, almost exactly, which it has to-day, seven and one-third miles above the bar. *Could the bar again re-form afterwards nearer than seven and one-third miles from the end of these artificial jetties?* Would there be less than sixty feet depth between them, as there is now between the natural ones? Suppose there was no littoral current or gulf stream to carry away the sediment, the bar would then certainly form again, *but when?*

At the rate it has been going out for the last forty years it would take the river 65,000 days, or 178 years, to extend its jetties from where they are finished, out to the present crest of the bar. All these years will be required to build up its foundations in the gulf before it can complete its jetties to the present bar. Is it not evident then that 178 years hence, if the river be left alone, the bar will then be seven and one-third miles in advance of its present location? Is it not equally evident, if man should do in three or four years what it will require the river 178 years to do, that when the bar reappears it will be after the lapse of centuries, because it *must be* located at least seven miles beyond the artificial jetties, and where the water is now several hundred feet deep? Even if there be no currents whatever to distribute the sediment into more profound and distant depths, we will have gotten so far in advance of the bar forming power of the river, that it will require centuries for it to overtake the work of man, and again build up its bar, for this must be done in greatly increased depths.

WILL JETTIES STAND?

One of the chief reasons urged against the jetty system is that they cannot be made to stand at the passes.

Their permanency will depend mainly on the skill and experience of the engineer who builds them. Works of this kind are con-

structed in various ways, according to the nature of the foundations on which they will rest and the casualties to which they will be subjected. To construct them wholly of stone on the bars of the Mississippi would be the sheerest folly. To build them of piles and planks would be equally unwise. The river itself is daily teaching us that it is able to construct jetties of sedimentary matters which the river transports, which are imperishable and constantly increasing in strength. On its banks are found millions of young willows and poplars which, properly formed into fascines, and securely interwoven in large masses, and sunk with stone in the line of the proposed jetties, and securely held in position by huge blocks of beton or concrete, which is but little heavier than the sediment itself, will soon become filled with sedimentary deposit, and form artificial banks indestructible as those nature is daily building at the passes.

This system of construction is being successfully practiced in Holland and elsewhere, on foundations of a character quite like that with which we have to deal. It is idle to predict the impossibility of making jetties stand on a bottom so firm as to hold ships when aground, against the most powerful tug boats that can be procured, and against the severest winds that sweep the gulf.

MUD LUMPS.

The sedimentary matters brought to the gulf by the river are deposited in proportion as the current diminishes. The silicious and heaviest particles fall first; the lighter ones are borne much farther seaward before falling. Consequently these lighter matters fall as soft as snow to the gulf bottom first, and are afterwards, by the bar advance, covered by the heavier ones. Immense quantities of microscopical vegetable matter fall with the light sediment, and chemical changes occur in consequence of their contact with the salts of the sea. As decomposition progresses beneath the more recent deposits, gases are produced, and following the lines of least resistance when liberated, they come to the surface. The accumulating weight of the deposit at the bars causes the creamy sediment which first fell to the bottom, and in which these gases are generated, to follow their track to the surface. If this discharge of gas and soft mud occur in the channel, the mud is gradually swept to the sea without man's knowledge; but, if it be in shallow, and consequently still water, the mud remains around the craters, and continued discharges elevate the mounds thus formed, until they are sometimes more than one hundred feet in diameter and fifteen or twenty feet high. A mud lump rarely occurs except near the bar, which indicates that, as the bar advances, the pressure causes the discharge of

gas and mud to be made, after which the power of further discharge at that particular locality is forever gone.

These mud lumps have been used to frighten persons not familiar with the subject into hostility to the jetties, on various ridiculous pleas. Whereas if one rose in the line of jetties no better work could be desired at that spot, and if it came up in the channel dredging would certainly remove it, if the current did not. Persons of great experience assert that but one was ever known to rise in the channel, and even that one is of doubtful authenticity. By those who are familiar with the facts, the mud lumps are deemed the most ridiculous absurdity yet advanced against the jetty system. The assertion that they possess any lifting power is utterly without foundation.

ARGUMENTS AGAINST THE JETTY SYSTEM.

One of the most earnest opposers of the jetty system is Major C. W. Howell, United States Engineers, who designed and strongly advocates the Fort St. Philip canal. The following extracts are from a letter addressed last May, by Major C. W. Howell, United States Engineers, to Captain J. H. Oglesby, President of the New Orleans Chamber of Commerce. Speaking of the jetty system, he says:

"The theory is attractive from its apparent simplicity, and for the same reason is the first to claim the attention of dabblers in hydraulic engineering, who either do not know, or else lose sight of the conditions essential to its successful application. The principal of these conditions are two. 1st. That the character of the bed and banks of the river, at the point of application, be such that scouring will be effected in the bed, in preference to the banks—in other words, the banks must be firm enough to withstand the action of the current, and the bottom yielding enough to permit scour.

"The second condition is, that there shall exist a current (littoral) passing the outer extremity of the jetties perpendicular to them, capable of sweeping to one side or the other all deposit made about the jetty heads and tending to form a new bar outside. No such current has been discovered at the mouth of the Mississippi, although carefully sought for. In default of it, jetties would have to be built further and further out, not annually, but steadily every day of each year, to keep pace with the advance of the river deposit into the gulf, provided they are attempted, and the attempt warranted by having the relative character of bed and banks favorable.

"For the reason that these two conditions are not to be found at the mouth of the Mississippi, careful engineers have time and time again pronounced the application of jetties at either Southwest Pass or Pass a l'Outre, not worthy of trial *at Government expense*. If enthusiastic jetty men wish to pass from theory to practice, they can always gain consent to spend *their own money* in building jetties at Southwest Pass, and if they succeed in doing good, they will have a fair claim on Government for recompense. * * * * *

"Jetties have once been attempted there, and not only reported a failure by the inspecting officer, but abandoned by Messrs. Craig and

Rightor, who made the attempt—the full particulars of this may be found in Ex. Doc. No. 5, Ho. of Reps., 36 Cong., 2nd Sess. The practical experience gained by that failure, I presume, will deter the Government, though it may not deter adventurous jetty men, from sinking more money in such attempts."

MAJOR HOWELL'S FOUR ERRORS.

Major Howell was doubtless not aware that he was making four misstatements in his letter to Captain Oglesby. They are as follows: 1. That the banks of the passes will scour away sooner than the bed of the stream. 2. That there are no currents capable of sweeping to the one side or the other the river deposit beyond the proposed jetties. 3. That "careful engineers have time and again pronounced the application of jetties at these passes unworthy of trial *at Government expense.*" 4. That the jetty system has once been tried at the Soutwest Pass, and proved a failure.

The idea that the banks will be scoured away is based upon the false assumption that the water will be permanently raised above the jetties. If this were true it would simply create the effect of a flood, and those who are not engineers know that the way the banks of the passes are built up above the ordinary surface level of the river, is by the overflows. Where there are no levees, every overflow contributes to the elevation of the bank of the stream. Each time the banks of the passes are overflowed, the reed-grass and plants on their marshy surfaces not only prevent abrasion, but they check the flow of the current and cause the deposit which is held in the water to be dropped on the banks. With parallel jetties five miles in length, it would be impossible to raise the water five inches, and any temporary elevation would subside with the deepening of the channel.

Major Howell's first statement is therefore evidently an error. The following paragraph from the elaborate report of Humphreys and Abbot (Phys. and Hyd. of Mississippi River), page 449, completely disproves his second statement:

GULF CURRENTS DO EXIST.

"The investigations of the Coast Survey have also shown that the tidal wave approaches the mouths of the Mississippi from a southerly direction. With this tidal wave there is near the coast a tidal current, in the same direction. The tidal wave lifts up the river current in the gulf, and the tidal current passes under it, though checking it to some extent in so doing. The direction of this tidal current is modified by its contact with the river current, and to a greater degree by its contact with the outer slope of the bar deposit. In the case of

the Southwest Pass, a flood tide brings a current from the southeast, which is changed to a southwest direction, more westerly than that of the river current, by the bar deposit along the eastern side of the mouth of the pass. The ebb tide is accompanied by a current from the opposite direction, which is similarly diverted by the deposit on the western side of the mouth of the pass, the direction being more southerly than the current of the river. Winds may change the direction and force of these currents, which, in mid-river current, at a depth of forty feet, are shown by the observations to vary from three-tenths of a foot to two and five-tenths feet per second, the mean being about five-tenths of a foot. *As a velocity of five-tenths of a foot per second is sufficient to transport the material of which the bar is formed, the action of the gulf currents in carrying into deeper water the material pushed by the river into the gulf is evident.*"

JETTIES HAVE NEVER BEEN TRIED AT THE MOUTH OF THE MISSISSIPPI.

The following extract from the same work (being a foot-note on page 455) disproves the other two statements made by Major Howell:

"Attention should here be directed to the fact that *the plan of jetties has not really been tried at the mouth of the Mississippi*, as the contractors merely built one insecure jetty of a single row of pile planks, about a mile long, whereas *the Board of 1852 recommended jetties* five miles long on each side of the channel, each fourteen and a half feet wide, composed of piles two feet apart. The plan has been tried, however, at the principal mouth of the Rhone, a delta river like the Mississippi, and has effected the desired increase of depth."

The italics, which are not in the report, are used here to impress these facts more fully on the memory of those who have been continually making counter statements.

U. S. BOARD OF ENGINEERS OF 1852 RECOMMEND JETTIES.

The Board referred to by Humphreys and Abbott, in this paragraph, was composed of Capt. Latimer, Capt. Chase, and Gens. Barnard and Beauregard. We see, therefore, that "careful engineers" *have recommended* the trial of the jetty system for the mouth of the Mississippi; and prior to the date of Capt. Howell's letter we believe no engineers of note had reported against them.

Humphreys and Abbott were certainly justified in saying that "the plan of jetties" had not been tried there; for all engineers know that the application of that system to any river mouth opening into the sea as the Mississippi does, with no banks above water, absolutely involves the construction of *two* jetties, one on each side of the stream; only *one*, however, an insecure pile plank dam on *one side* of the mouth seems to have been sufficient to justify an engineer in speaking of it *in the plural*, and declaring to the people of New Orleans that "jet-

Engineers, and the other, the jetty system, by myself and others. The subject was referred by Congress to a mixed commission, composed of seven distinguished military and civil engineers, who, after careful deliberation, reported (one member only dissenting) in favor the jetty system: whereupon Congress granted to myself and associates the right to improve the South Pass, an outlet unused for commerce; the grant expressly stipulating that we are to be paid nothing in case of failure to secure 20 feet depth of channel through the Pass to the gulf, within a stated period. The act directs the Secretary of War to appoint an officer "whose duty it shall be to report the depth of water and width of channel secured and maintained from time to time, in said channel, together with such other information as the Secretary of War may direct."

The grant expressly provides that "I shall be untrammeled in the exercise of my judgment and skill in the location, design and construction of the works," therefore I did not suppose that another officer of engineers, and one, too, avowedly hostile to the undertaking, would likewise (without authority of Congress) be charged with the official duty of observing any part of our work or its results. Least of all did I suppose that he would be permitted to give to the public with perfect freedom such unfavorable and unreliable information respecting it as might best seem to support the predictions of its failure previously uttered so confidently by his chief and himself, and thus really trammel its construction by increasing my difficulties in providing means with which to carry it on.

Anonymous statements circulated in this city and subsequently sent hence by telegraph have been published in a number of newspapers through the country, to the effect that a new shoal was forming in advance of the jetties and that their failure was therefore certain. This report, being persistently repeated, was publicly denounced by me, with, perhaps, too much feeling, as a "malicious falsehood," but without supposing that Major Howell was at all responsible for the statement. Appreciating the importance, however, of refuting such reports by evidence that could not be challenged, I addressed the superintendent of the United States Coast Survey as follows:

"NEW ORLEANS, March 7, 1876.

"*Capt. C. P. Patterson, Superintendent U. S. Coast Survey, Washington, D. C.:*

"DEAR SIR,—Last year Lieut. Marinden made soundings on radial lines seawards from the bar of South Pass. I very much desire that these radial soundings should be repeated before Lieut. M. leaves here, and I think you will agree with me that it is important to know where the one or two millions of cubic yards of sandy alluvion, which have been swept out of South Pass from its bar, have been carried and

deposited, and what changes, if any, have occurred in the contour lines off the mouth of South Pass.

"Radial lines of soundings should be made from the east and west lands' ends out to two or three miles off shore.

"Hoping that you will kindly oblige me by ordering this work to be done by Lieut. M., I remain, with sentiments of high esteem,

"Yours, Very Truly,

"JAS. B. EADS."

In answer I received the following reply:

"U. S. COAST SURVEY OFFICE,
"WASHINGTON, D. C., March 10, 1876.

"DEAR SIR,—Yours of the 7th is just received.

"Authority will be given to Assistant Marinden to run such radial lines as you may wish, but as he has not the control of a steam launch this season, only his boats avail for the purpose, and consequently he should run merely such lines as may be absolutely necessary.

"If you could furnish him the use of a small steamer, the work could be executed more rapidly, and doubtless with more satisfaction to you and himself.

"The state of our funds does not enable us to incur the expense of a steamer.

* * * * * * *

"Yours Respectfully,

"C. P. PATTERSON,

"Supt. U. S. Coast Survey.

"JAS. B. EADS, C. E., New Orleans, La."

I agreed to furnish the necessary steamboat and these soundings have now been nearly completed.

On the 26th ult., a large party, comprising many influential gentlemen, visited the jetties on the mammoth steamer Grand Republic. It was stated in the *New Orleans Times*, after the return of the boat to New Orleans, that an assistant of Major Howell had gone on board the boat at the jetties, with a chart of soundings just taken by him, which he exhibited and explained to the passengers. I was assured by several prominent citizens of New Orleans, whose names will be given if desired, that his apparently reliable and official statements had created great distrust in the ultimate success of our work throughout the whole city, as it was generally belived Major Howell's surveys revealed a rapidly forming shoal in advance of the jetties. I was reliably informed that a large amount of stock subscribed in aid of our undertaking was actually offered at the time at half its cost in consequence, and I myself received at the same time a letter asking

the release of one of the parties aiding it, from his obligation to pay a large balance due on his subscription.

Knowing the importance of promptly refuting by official testimony these misrepresentations, I immediately addressed the following additional request to the Superintendent of U. S. Coast Survey:

"PORT EADS, LA., April 27, 1876.

"*Capt. C. P. Patterson, Washington, D. C.:*

"DEAR SIR — As the changes within our jettied channel have been very great since Assistant Marinden surveyed the bar, I would respectfully suggest the importance of having his party sound the depth within the jetties and within a thousand feet of their mouth.

"This work can be done with much greater ease and much quicker now than before, as I have signal ranges and stations established by which my assistant engineers make these soundings in two days time generally. I will be much obliged if you will order this work to be done as early as possible, and instruct Assistant Marinden to furnish me a copy of the results. He is now here preparing for the radial soundings beyond the jetties. I will loan him facilities for all the work.

* * * * * * *

"Very Respectfully,

"JAS. B. EADS."

Feeling indignant and outraged at the unwarranted conduct of Major Howell's assistant, I published a letter in the *New Orleans Times*, herewith enclosed (marked B) in which I again pronounced the reported shoaling in advance of the jetties as absolutely false. I had, however, so much confidence in Major Howell's honor, and in the delicate sense of propriety which characterizes gentlemen of the army, that I exonerated him in the following language, in the letter, from any complicity in this effort to injure me and my associates. I said:

"But as these works are not under the supervision of Major Howell, it is unjust to him to infer that he has authorized any of his assistants to make an 'official' survey of the South Pass bar at the government's expense, or that he would countenance on the part of his assistant, any effort to create in the minds of the visitors by the Grand Republic or in those of any other persons whatever, the false impression that this bar, which has thus far been removed by the effect of the jetties, is being reformed in advance of them, or that he would, as readers of your editorial might possibly suppose, permit the draft of such soundings to be exhibited on the Grand Republic or in his office, with any show of 'official sanction.'"

An editorial herewith inclosed (marked C) shortly afterward appeared in the *New Orleans Democrat*, containing statements that could only have been obtained in Major Howell's office, and which apparently

sustained this false report. I immediately answered the editor of the *Democrat* by letter, a copy of which is herewith inclosed (marked D), that this and similar reports had their origin either in ignorance or malice, as they were absolutely untrue. I did not, however, even then charge Major Howell with being the author or prompter of them.

This second letter was followed by the publication of the inclosed objectionable letter of Major Howell, before referred to. Major Howell declares in this letter:

"On my own part this considerate silence would not have been broken but for the recent insidious attacks of Mr. Eads, and after this date I shall feel at liberty to either repel further attack or let the violence of Mr. Eads of itself gradually disgust the public."

As "the recent insidious attacks of Mr. Eads" seem to be the only justification offered by Major Howell, you will, after reading my published letters herein referred to, be able to judge of the merits of this excuse. Of course I cannot reply to Major Howell's personalities, for when an officer of the army makes statements that are untrue, and uses his official signature to give them additional weight, discussions that might otherwise be justified between us, are at once forbidden. These untrue statements are as follows:

"The fact is, that on the day of the Grand Republic splurge there was at South Pass only a channel of twelve feet entitled to be called navigable, while at Southwest Pass there was a navigable channel of over eighteen feet.

"I know that on the day the Grand Republic visited South Pass the nucleus of a new bar existed 1,000 feet in front of the jetties, and that a shoal had made out from the end of the west jetty 380 feet towards this, and diagonally across the front of the jetties.

"I know that since the commencement of the jetty work the low water cross section of South Pass, one mile below its head, has been diminished one-sixth; that the velocity at this point has relatively decreased, and that the volume of discharge of the pass which, before commencement of the jetties, was found to be fifteen per cent. of the total discharge of the three passes, is now but eleven per cent. Mr. Eads has probably discovered these facts, having such a serious bearing on the ultimate success of his work, and knowing that they will soon be made public through official channels, seeks in advance to break their force by crying out 'malice,' 'falsehood,' etc."

A direct and positive refutation of four of these untrue and injurious statements will be found in the following letters from three of the gentlemen assisting me in the engineering department of the work, and who are no less respected for their veracity than for their professional abilities.

"NEW ORLEANS, May 22, 1876.

"*Capt. J. B. Eads, Chief Engineer South Pass Jetty Works, New Orleans, La.:*

"DEAR SIR — The statements of Major Howell, United States Engineers, contained in his letter recently published respecting this

work, having been referred by you to me for examination, I have to state that there has been no shoaling in advance of the jetties, but on the contrary, there has been a very marked and general increase in the depth immediately in front of the outer slope of the bar in advance of the jetties as far out as we have made accurate examinations, nearly 2,000 feet beyond the jetties. I am able so assert this in the most positive manner, as we have a number of carefully located ranges covering the bar and the deep water in front of it, and I have made careful soundings all over it at least once and sometimes twice a month for several months past, each sounding at the moment it was taken being located instrumentally from fixed and well verified points of observation. I am able to state positively that there has, at no time since we commenced work, been any shoal making out diagonally from the west jetty towards the so-called 'nucleus of a new bar' in advance of it, as stated by Major Howell.

"I can also state positively that what he terms 'the nucleus of a new bar, 1,000 feet in front of the jetties,' is the remains of a lump shown on the Coast Survey map before we began the jetties, and from approximately correct estimates made by me, after comparing, as carefully as possible, the depths over it a year ago, with those now existing on it, that the cubical contents of it above a plane thirty feet below the mean level of the Gulf have diminished nearly one-half. The depth on the shoalest part of it, which is a mere point or apex, was last year fully three feet less than it is at present. This lump seems to be soft, tenacious clay. It has deep water all around it, and constitutes no impediment to the safe and easy navigation of the jettied channel.

"I have further to state that I have made recent soundings across the South Pass, one mile below the head of it, at the point referred to by Major Howell, and compared them with those of the Coast Survey of last year. I find no such diminution of its section as Major Howell has stated. It has certainly not decreased, since the jetties were commenced, at this point. I have also made careful soundings across the pass below Grand Bayou, before the section of the bayou was reduced by the dam now partially completed, and which now throws an additional quantity of water into South Pass, and found it considerably larger than the size shown by Coast Survey soundings made last year.

"I would further state that on the day when the Grand Republic visited the jetties there was a navigable depth of fully sixteen feet entirely through the jetties at high tide. It was measured by myself and several other persons on that day and the day previous.

"Very respectfully, etc.,

"E. L. CORTHELL,

"Chief Assistant Engineer."

"I fully concur in the statements made by Mr. Corthell, and certify to their correctness. I myself superintended the taking of a line of soundings into the pass between the jetties on the day the Grand Republic visited Port Eads, and in no place found a less depth at average high water than sixteen feet, with only one place so shoal as that.

"Very truly yours,

"G. W. R. BAYLEY,

"Resident Engineer.

"New Orleans, La., May 22, 1876."

"PORT EADS, LA., May 23, 1876.

"*Capt. Jas. B. Eads, New Orleans, La.:*

"I have assisted Mr. E. L. Corthell in all the surveys that have been made under his direction at the mouth of South Pass. I have mapped them out carefully, and from my own studies of the changes that have occurred inside and outside the jetties, I can fully indorse Mr. Corthell's statements and testify to their correctness.

"Very respectfully, your obedient servant,

"MAX E. SCHMIDT,

"Assistant Engineer South Pass Jetty Works."

About the time Major Howell published his letter, I received the following courteous refusal of my second request from the Superintendent of the Coast Survey:

"UNITED STATES COAST SURVEY,
WASHINGTON, D. C., May 1, 1876.

"Dear Sir,—Your letter of April 27th is duly received. I would cheerfully comply with your wishes, but the law expressly provides that the inspecting officer of the Engineer Corps (Gen. Comstock) shall execute the class of surveys you wish within the jetties.

"The radial lines from the outer ends of the jetties were run at your request, for the purpose of finding, if possible within their limits, the deposit of removed material.

"I shall be glad to offer any assistance in my power to Gen. Comstock, should he express a wish for the survey to which you refer.

"Yours respectfully,

"C. P. PATTERSON,

"Supt. U. S. Coast Survey.

"*Jas. B. Eads, Esq., New Orleans.*"

Immediately after the visit of the Grand Republic, Capt. Brown, U. S. Engineers (assistant of Gen. Comstock), commenced a survey of the bar, and believing that information in his possession would completely refute Major Howell's assertion, I asked him for an

official statement of the depths of channel at that time. This he declined to give, stating as a reason that he had not made his report to Gen. Comstock. Learning that the latter officer had just gone to the jetties, I telegraphed the Secretary of War as follows:

"NEW ORLEANS, LA., May 9, 1876.

"*Hon. Alphonso Taft, Secretary of War, Washington, D. C.:*

"Please instruct Gen. C. B. Comstock, now at Port Eads, to sound channel between jetties with me; likewise dredged channel through Southwest Pass bar, and furnish me with results promptly. Major Howell has published a misstatement, affecting public confidence in my work, and this information is required in justice to myself, and will benefit the public.

"JAS. B. EADS."

I proceeded to the jetties, and met Gen. Comstock on his way back. I urged his return, that he might measure the channel with me, if so authorized by the Secretary of War. On my urgent declaration that a wrong had been done me, and one that was seriously affecting the prosecution of the work, Gen. Comstock consented to return, and remained during the day at the jetties awaiting instructions; but as no answer to my dispatch came, he left that evening for New Orleans. He declined to give me any information respecting the depths in question, for the reason that he had not yet made his report to Gen. Humphreys. Four days after sending my dispatch to the Secretary of War I received the following telegram:

"WASHINGTON, May 13, 1876.

"*Mr. Jas. B. Eads, New Orleans, La.:*

"In accordance with the law, Gen. Comstock received authority and instructions for complete survey and examination of the South Pass improvement before leaving Detroit. A copy of the results of his soundings will be furnished as soon as received.

"ALPHONSO TAFT."

On the receipt of this telegram I dispatched to the Superintendent of the Coast Survey, requesting that Mr. Assistant Marinden be permitted to inform me of the result of his soundings just made, chiefly at my own expense, in advance of the bar. In reply I received the following telegram:

"WASHINGTON, May 16, 1876.

"*Capt. Jas. B. Eads:*

"Regret Marinden can not furnish his results. Gen. Comstock will give all information required by law. Will write.

"C. P. PATTERSON, Supt., etc."

It will be seen that I have been unable at the end of three weeks to obtain from any Government officials the facts in their possession or control, with which to defend this enterprise from the persistent and injurious misrepresentations that have appeared anonymously, semi-officially, and authoritatively during the last few weeks, and that I have been refused the request to direct Gen. Comstock, when on the spot, to measure and certify to me the depth of channel, to right a wrong done by his brother officer. In prominent contrast with the difficulties I have encountered in getting this official information, which would have been of great value to me if promptly obtained, I quote the following from the letter of Major Howell regarding his surveys:

"The surveys have been made at Government expense, because needed to aid in solving the great problem presented at the mouth of the Mississippi."

"If the results had been available before the passage of the jetty contract, it is probable that the country would not have been saddled with the adventure."

"My charts, observations for velocity of currents, amounts of material carried in suspension by the river water, and volumes of discharge, have always been open for the inspection of any courteous gentleman interested in seeing them. In this there is no impropriety, as Mr. Eads would insinuate."

I have no reason whatever to complain of the course pursued by Capt. Patterson, Gen. Comstock, or Capt. Brown in this matter, as it has been, I believe, in strict accordance with official propriety.

Major Howell says:

"I know that between distances two and a half and seven and a half miles seaward of the outer end of his jetties the Gulf has shoaled at a rate which, if continued, will in eighteen high-water seasons bring the Gulf bottom to the surface, and necessitate the prolongation of the jetties at least seven and a half miles."

When it is understood that this reputed shoaling was known before the jetties were commenced, and that no soundings have been made over it since last November, to determine whether it is increasing or diminishing, at which time the eroding action of the jetties had scarcely begun, its "serious bearing upon the ultimate success of his (my) work" can be estimated, as well as the fairness of the writer in leaving his readers to infer that this shoaling is an evidence of the truth of the prediction of himself and his chief regarding the re-formation of the bar.

An extension of the jetties of seven and a half miles in eighteen years, or nearly six feet per day, would not be incompatible with the following assurance given to the New Orleans Chamber of Commerce by Major Howell, and which will be found in his letter to Mr. J. H. Oglesby, president, that, as no littoral current exists at the mouth of the Mississippi, "jetties would have to be built further and further

out—not annually, but steadily every day of each year—to keep pace with the advance of the river deposit into the Gulf, provided they are attempted and the attempt warranted by having the relative character of bed and banks favorable."

I quote again from Major Howell's inclosed letter, as follows:

"Holding these views, no army engineer has thrown a straw in the way of Mr. Eads' jetty work."

This is another misstatement. *After the jetty system was finally adopted by the last Congress*, General Humphreys published four essays, termed by him "memorandums," to prove that the jetties would be a failure; these were published as a part of his official report to the present Congress. They were at the same time extracted from that voluminous document and illustrated with maps, were bound in pamphlet form and distributed throughout the country five months ago. To counteract the injurious effect of these private opinions of Gen. Humphreys, to which he gave all the weight of his official titles and position, I deemed it necessary to expose the fallacies upon which his arguments were founded by reviewing the United States Levee Commission's report, which was based upon the same unsound theories, and to which report he had given his emphatic approval.

Major Howell endeavors to excuse this conduct of his chief in the closing words of the following extract:

"Since the passage of the late jetty contract those opponents of the experiment who took part in the discussions preceding the passage of the contract, considered first that they were in no way responsible for the experiment. Second, that further discussion would be useless, except so far as required to complete that left unfinished by the action of Congress."

Admitting Gen. Humphrey's ability to complete discussions left unfinished by Congress, his justification in this case would have been more satisfactory had Major Howell informed his readers by what authority an officer of the United States Engineers presumes to publish his gratuitous opinions at the public expense, or to indirectly criticise the President and Congress of the United States for declining to be guided by the judgment of General Humphreys and Major Howell in this matter.

But few persons inexperienced in the difficulties of raising the large amounts of money required in works of great magnitude, can appreciate the injurious effects of unfavorable arguments or apparently well authenticated reports against an enterprise, especially when they involve, if correct, the certain loss of capital invested. For several weeks past we have, through the self-acknowledged conduct of Major Howell, been seriously trammeled in the prosecution of the works we are constructing, by misrepresentations to which have been given a real or seeming assurance of official truth, while it has been out of my power to obtain, officially, the real facts to disprove them.

In view of the annoyance and embarrassments already suffered from the official antagonism of Gen. Humphreys and Major Howell, and of the fact that their official positions give them the ability to continue their open or insidious opposition to this work (the one being Chief of the Corps of Engineers, U. S. A., and the other stationed in this city in charge of important engineering operations in the vicinity), I have to respectfully ask that any further officious or unauthorized official interference on the part of these officers, be interdicted, and that instructions be issued to the inspecting officer authorized by the act, and "detailed" by you to make the examinations, to promptly supply me with any official information he may from time to time acquire respecting these works, and their results, which I may deem important to facilitate us in carrying out the intent of the grant, or in protecting us from misrepresentation; and that his reports hereafter be made directly to the Secretary of War, instead of through the medium of the Chief of Engineers, U. S. A., as the Secretary of War alone is, by the words of the grant, "authorized and directed to carry into effect the provisions of the act."

We are assuming all risks and expending our own money under a grant which gives us no power to deceive the government, even if we desired to. Our compensation depends wholly upon results to be achieved, and upon the good faith of the government. We were entitled to eight months to commence the work, and thirty months within which to secure twenty feet of depth, yet before fifteen have elapsed the largest coasting steamers trading to New Orleans have been sent to sea over the bar on which scarcely eight feet of water could be found last year. We have thus shown an energy and good faith not only entitling us to the moral support of the government, but to its confidence. I cannot believe for a moment that the policy of your department will, with your sanction, be allowed to embarrass me in the prosecution of a work of such immense importance, when the untrammeled control of it was confided to me by the almost unanimous action of Congress, and the approval of the President of the United States.

I have the honor to be, very respectfully,

Your very obedient servant,

JAMES B. EADS.

APPENDICES.

(A.)

UNITED STATES ENGINEER OFFICE,
NEW ORLEANS, May 6, 1876.

Editor New Orleans Democrat:

Your editorial of the 3rd instant, elicited by the lengthy telegram from Mr. James B. Eads, which appeared in the New Orleans *Times* of April 30, has provoked Mr. Eads into writing a letter (published in your issue of the 4th inst.), which is calculated to create a wrong impression on the minds of the public.

Mr. Eads is mistaken in supposing that because he has a contract to try to improve South Pass, this fact bars me from continuing to completion a series of surveys made, commenced under orders received two years ago. The series would have been incomplete without the recent gauging of the passes and reconnoissance of South Pass bar.

The results, when fully submitted to the public, will greatly interest hydraulic engineers, and go far toward refuting many of the absurd statements and theories advanced by Mr. Eads before commencing his jetties, and on which all his specious plans are based.

Perhaps this is the reason why, in his usual brow-beating manner, with which the people of New Orleans are so familiar, he attempts to choke off investigation.

The surveys have been made at government expense, because needed to aid in solving the great problem presented at the mouth of the Mississippi.

If the results had been available before the passage of the jetty contract, it is probable that the country would not have been saddled with the adventure.

My charts, observations for velocity of currents, amounts of material carried in suspension by the river water, and volumes of discharge, have always been open for the inspection of any courteous gentleman interested in seeing them. In this there is no impropriety, as Mr. Eads would insinuate.

The insinuation in regard to the St. Louis telegram is one that no just man would give such publicity without first satisfying himself as to the facts. I have not seen a copy of the telegram; do not know what it contained; but I know this, that if the information on which it was based came from my office, and was honestly used, instead of being, as styled, "a malicious falsehood," it was the unpalatable truth.

The more direct charge that my assistant endeavored to create among the guests and passengers of the Grand Republic an impression unfavorable to the jetties, is equally without foundation.

After investigating the matter, I find these to be the facts: Mr. Collins, having completed his field work, in accordance with his instructions to return to New Orleans as soon as possible, took passage on the Grand Republic, paid his fare, simply answered questions when courtesy required it, and was an interested observer of the solemn farce entitled "Colonel Andrews' examination."

There was no volunteered attempt on his part to influence the minds of the St. Louis delegation against their "Josh," his work or his teachings.

By implication, the accuracy of the work done by my assistants has been brought in question.

Mr. Collins has been with me over four years. He has worked in the field with three of my military assistants, who report him to me as an accurate, rapid and extremely conscientious engineer. I place full faith in his reports.

The results of dredging at Southwest Pass are very unfairly presented.

The reported mean low tide depth at Southwest Pass is introduced in such artful connection with a reported high tide depth at South Pass, that the casual reader would be led to think the depth of channel at the two passes the same; whereas, the fact is, that on the day of the Grand Republic splurge there was at South Pass only a channel of twelve feet entitled to be called navigable, while at Southwest Pass there was a navigable channel of over eighteen feet.

Now, let me give my understanding of the position held by Mr. Eads and the opponents of his jetty attempt. It may give the public something worth thinking over.

I know that between distances two and a half and seven and a half miles seaward of the outer end of his jetties the Gulf has shoaled at a rate which, if continued, will in eighteen high water seasons, bring the Gulf bottom to the surface, and necessitate the prolongation of the jetties at least seven and a half miles.

I know that on the day the Grand Republic visited South Pass the nucleus of a new bar existed 1,000 feet in front of the jetties, and that a shoal had made out from the end of the west jetty 380 feet toward this and diagonally across the front of the jetties.

I know that since the commencement of the jetty work the low water cross section of South Pass, one mile below its head, has been diminished one-sixth; that the velocity at this point has relatively decreased, and that the volume of discharge of the pass which, before commencement of the jetties, was found to be fifteen per cent. of the total discharge of the three passes, is now but eleven per cent. Mr. Eads has probably discovered these facts, having such

a serious bearing on the ultimate success of his work, and knowing that they will soon be made public through official channels, seeks in advance to break their force by crying out "malice," "falsehood," etc.

Since the passage of the late jetty contract those opponents of the experiment who took part in the discussions preceding the passage of the contract, considered first that they were in no way responsible for the experiment. Second, that further discussion would be useless, except so far as required to complete that left unfinished by the action of Congress. Third, that as the experiment had been decided upon, it was every way desirable that it should be carried to completion, in order that a question which has embarrassed the mouth of the river problem for forty years, and which might do so for an indefinite time to come, should be practically settled one way or the other, beyond resuscitation.

Holding these views, no army engineer has thrown a straw in the way of Mr. Eads' jetty work.

His "outside speculations" regarding the closure of the "Jump" and "Cubit's Gap," and his crude ideas about the improvement of the upper river, have been criticized, but his jetty adventure has been let alone. It now appears that it has been let too much alone to suit his present purposes.

On my own part this considerate silence would not have been broken but for the recent insidious attacks of Mr. Eads, and after this date I shall feel at liberty to either repel further attack, or let the violence of Mr. Eads of itself gradually disgust the public.

In closing, I offer an opinion, which perhaps I am not alone in holding.

The repeated cries of "success" which we have heard from the very commencement of the jetties are deceitful. There can be no success except of a United States Treasury raid until it is ascertained that the jetties are of a permanent character and afford something more than a temporary outlet to the commerce of the Mississippi valley.

I am, sir, very respectfully yours,
C. W. HOWELL,
Captain of Engineers, United States Army.

(B.)

PORT EADS, April 29, 1876.

Editor New Orleans Times:

In reading your editorial of Friday morning, I observe that in alluding to the soundings made through the channel across the bar of the South Pass, in the presence of Captain Thorwegan and a number of distinguished passengers on the Grand Republic, you say,

"from this it seems plain that a vessel drawing sixteen feet can go to sea through the jetties at mean low tide any day." * * * "All this was very gratifying and encouraging to the visitors. Only one ugly feature was to be observed, and that was a draft of soundings made by an assistant of Captain Howell on the morning of the same day, which draft is said to be now in Capt. Howell's office." You state in the editorial that this draft of Capt. Howell's assistant shows soundings 400 feet out from the sea end of the jetties, and that the water shoals up there suddenly to 16 feet. You add these words: "Assuming these soundings to be official and correct,the general impression would be that a new bar is forming, not on the sea slope of the old one, but on the other side of a narrow sound, across which the swift current of the river carries its sediment to be suddenly dropped at a certain distance out. This is a very disagreeable feature of the case, and we sincerely hope it may be satisfactorily explained away. If it cannot, the sooner the fact is known the better." It is only two days ago that I authorized the Secretary of the South Pass Jetty Company to state, in reply to telegrams sent from New Orleans to St. Louis, and published in the papers of the latter city, "that the reported shoaling in front of the jetties was a malicious falsehood." I was justified in thus emphatically expressing these anonymous misrepresentations, by recent soundings carefully made by my assistant engineers, within a thousand feet of the sea end of the jetties and beyond the bar.

These soundings were carefully located by instruments, and were compared with those made one year ago by the United States Coast Survey. They prove conclusively that there has been a general deepening in advance of the bar in front of the jetties, precisely where General Humphreys, Major Howell and other opposers of the jetty system predicted a re-formation of the bar. The deepening is shown by these soundings to be several feet in depth over an area of 1,000,000 square feet beyond the outer slope of the bar. At my solicitation the Superintendent of the United States Coast Survey, Captain C. P. Patterson, has instructed Assistant Marinden, United States Coast Survey, who made the survey last year, to run out radial lines of soundings from the sea ends of the jetties to a distance of three miles, or into about thirty fathoms of water, for the purpose of ascertaining what deposit has been made within that distance since we commenced work. This duty Mr. Mariden is to-day performing, and the results will, I presume, be promptly furnished to the public by the Superintendent of the Coast Survey, through the proper department. The steamer employed in this service is furnished by me. The cause of the remarkable deepening which our soundings have discovered immediately in advance of the bar, is attributed by me to the fact that the river current, now concentrated between the jetties, is a strong, bold stream, from 12 to 16 feet deep, possessing such momentum and force

that the prevailing westerly sea current, which intersects it nearly at right angles, is forced beneath the river discharge and has excavated for its own accommodation an increased depth on the sea slope of the bar. Before we began work the river discharge constituted but a feeble and shallow film of water, several thousand feet wide and only two or three feet in average depth, and would oppose but little resistance to the sea current. With this dispatch, I have directed to be handed to you a lithographic plot of the United States Coast Survey soundings of last May, on which are shown the jetty lines also; several hundred copies of these charts have been sent by me during the past six months to parties interested in the enterprise, with our own soundings marked thereon, to show them the changes in the depth from time to time. You will see from this chart that about 800 feet in advance of the jetty line the Coast Survey soundings show a small shoal spot, on which there was then only 12 feet of water. Upon the shoal, Capt. Howell's assistant, it seems, found 16 feet last Wednesday. As the greatest depth across the crest of the bar is only claimed to be 16 feet 4 inches, it would seem unreasonable that the river current should have scoured off more than 3 or 4 feet of this shoal 800 feet in advance of the bar crest, because the river current cannot act outside the jetties at any greater depth than that at which it flows on over the bar crest, the river water being of lighter specific gravity than that of the sea.

This depth of 16 feet, which really is on this spot to-day, indicates the very opposite of what you fear and what the jetty opposers so emphatically declared would occur. It does not indicate in the slightest degree any re-formation of the bar beyond the jetties, but on the contrary, it proves that so fast as the compact current of the river deepens the crest of the bar, it likewise cuts down this solitary lump, which the Coast Survey sounding of last year discovered in the deep water of the Gulf immediately in advance of the jetties, which will disappear in due season, and which to-day has from 30 to 40 feet of water all around it. I was informed that Major Howell's steam launch, 'Survey,' had come around into South Pass on the day the 'Grand Republic' was expected here, and that his assistant had taken some random soundings through the jetties at that time, and that a draft of these soundings was exhibited to the passengers of the 'Grand Republic,' which you say "was the only ugly feature of the occasion." But as these works are not under the supervision of Major Howell, it is unjust to him to infer that he has authorized any of his assistants to make an "official" survey of the South Pass bar at the government's expense, or that he would countenance, on the part of his assistant, any effort to create in the minds of the visitors by the 'Grand Republic,' or in those of any other persons whatever, the false impression that this bar, which has thus far been removed by the effect of the jetties, is being re-formed in advance of them, or

that he would, as readers of your editorial might possibly suppose, permit the draft of such soundings to be exhibited on the 'Grand Republic,' or in his office, with any show of "official sanction."

JAMES B. EADS.

(C.)

THE JETTIES.

[From New Orleans Democrat, May 8, 1876.]

Captain Eads comes out in a communication to the *Times*, in which he reiterates his assurances concerning the condition of the jetties, and refutes the statements of other people, and he takes occasion to say that he has instructed the Secretary of the South Pass jetties to state, in reply to telegrams from New Orleans to St. Louis, "that the reported shoaling in front of the jetties was a malicious falsehood." Further on Capt. Eads says: "But as these works are not under the supervision of Major Howell, it is unjust to infer that he has authorized any of his assistants to make an official survey of the South Pass bar at the government's expense, or that he would countenance on the part of his assistant any effort to create in the minds of the visitors by the 'Grand Republic,' or *in those of other persons whatever* (the italics are ours), the false impression that this bar, which has thus far been removed by the effect of the jetties, is being re-formed in advance of them, or that he would, as the readers of your editorial might possibly suppose, permit the draft of such soundings to be exhibited on the 'Grand Republic,' or in his office, with any show of 'official sanction.'" Certainly, in penning the above quotations, taken from his communication, Captain Eads was reckoning without his host, as the saying is, and his deductions in the last paragraph must fall to the ground when he is informed that the drafts of the soundings of Major Howell's assistant, Captain Collins, are exhibited in his office with a considerable show of "official sanction." In fact, the soundings are made "officially" at the government's expense, and are part of a series of coast surveys which are under Major Howell's supervision, although the jetty works may not be; and if Capt. Eads doubts the truth of this statement, he can visit the office of Major Howell and satisfy himself. He will find there charts made from time to time of the South Pass, of so elaborate a character, that he will confess that, by comparison, his own lithographed charts must pale before them. It is useless to refer to the "malicious falsehood" portion of Capt. Eads' communication, in so far as it might affect those "other persons whatever," also spoken of by him. These utterances were made under circumstances which exist no longer, since it is now told to Capt. Eads that the reports, or some of them at least, were based

on the "official" figures of the Engineer Department. That Capt. Eads is entitled to belief when he asserts that his soundings are true, nobody will deny; but credit is also due to Major Howell and his assistants in the same relation. If, however, the question of correctness is raised on the score of favor or opposition to the jetty system, Mr. Eads' position becomes delicate, but that of Major Howell remains unchanged, whatever may occur in the case of the opposers of the system; Captain Eads is largely interested in the success of the jetties. His money and that of his friends, to the tune of several hundred thousand dollars, is jeoparded, and his reputation is involved. He has everything to lose. Major Howell, like all engineers of his ability, may and must have his theory on the subject, but he has neither money nor reputation involved. He is simply performing a duty. If, in performing this duty, the results conflict with those obtained by Capt. Eads, there can be no impropriety on the part of the department engineers to give access to their records, when politely requested to do so.

Now, to facts: they are few but important. During last week, as was stated in the *Democrat*, Captain Collins was engaged in taking soundings of the pass, and yesterday had already compiled and collated a good portion of his work. This compilation shows that the west end shoal, which a year ago was 800 yards beyond the end of the jetty, was, on the 26th of April last thrown out to 1,000 yards, and from the radial soundings taken by the same officers, exactly 380 feet out of the jetties; the bar has simply been pushed out—slope, shoal and all—as though it had been bodily removed from one point to another, showing, however, a difference in favor of Capt. Eads, at the crest of the present bar, of something like a foot in depth of water. But it is shown by the profiles that the crest of the shoal, as it existed a year ago, was a mere peak, the crest of which has easily ceded to attrition. Again, it is shown by the same profile that the breadth of the shoal, as it is now, is considerably increased, and hence will require more force to be removed than previously.

That the soundings have been carefully and elaborately made by the United States engineers will be understood when it is said that they have been made in ten longitudinal sections, 100 yards wide each (the width of the jetties being 1,000 yards), according to the regulation instructions of the War Department. The profiles are complete, and with their aid, and after making all due allowances, Major Howell has traced a possible 15 foot channel to the west end of the jetties, where the depth, the shoal, is about 16 feet. He has, however, been unable to trace a similar channel to the east end, where the depth of water is far greater.

As to the volume of discharge upon which Capt. Eads depended so much to scour out the channel of the jetties, Major Howell's belief that it had diminished in the South Pass and increased in the South-

west Pass has been verified by actual measurement. The velocity was taken one mile below the head of South Pass and below Grand Bayou. In Southwest Pass, it was taken at Scott's, two and a quarter miles below the head of the Pass. Major Howell's assistants have besides discovered, also by accurate measurement, that the increase in the area of water in Southwest Pass was on the 26th of April fifteen per cent, above last year's measurement, while in South Pass the increase was only one-tenth, notwithstanding that the Mississippi is much higher at this period than when the measurements were taken last year.

In connection with the condition of South Pass the following is given, showing that of Southwest Pass:

"UNITED STATES ENGINEER OFFICE,
NEW ORLEANS.

MEMORANDUM.

"During the month of April, 1876, the depth of the channel at Southwest Pass, at mean low tide, was 16 feet, with a least width for that depth ranging from 40 to 100 feet.

"High tides ranged above mean low tide from two to two and a half feet, making the depth of channel at high tide range from eighteen to eighteen and one-half feet.

"The dredge boat McAlister worked on the bar during the month 81 hours and 50 minutes.

"The following number of vessels crossed the bar during the month:

Steamers in	27
Steamers out	24
Sailing vessels in	41
Sailing vessels out	92
Total	184

"Of these 16 drew from eighteen feet to 18 feet 9 inches. Of this number, 9, drawing 18 feet and over, were detained an aggregate of 76 hours; 7, drawing less than 18 feet, were detained an aggregate of 131½ hours."

(D.)

A PERMANENT INCREASE IN THE DEPTH ON SOUTH PASS BAR.

NEW ORLEANS, May 3, 1876.

Editor New Orleans Democrat:

I have read your article in this evening's *Democrat* by which your readers are informed that official soundings of the South Pass bar

have been elaborately made by Major Howell, United States Engineers. You say: "In fact the soundings are made officially at the government's expense, and are a part of a series of coast surveys which are under Major Howell's supervision, although the jetty works may not be."

This is the first declaration I have seen published to the effect that Major Howell, United States Engineers, is also making official soundings of the Pass, and your editorial seems to go into such details as to leave but little doubt that you have obtained your information from his office, as you say if I will go there I will find "charts there, made from time to time, of the South Pass of so elaborate a character that he (I) will confess that, by comparison, his (my) own lithographed charts must pale before them."

Gen. C. B. Comstock, United States Engineers, was appointed by the Secretary of War to discharge the same duty which, it seems by your editorial, is being performed by Major Howell and his assistants. Gen. Comstock's assistant, Capt. M. R. Brown, United States Engineers, and party were yesterday engaged at the jetties in making elaborate soundings by order of the War Department also, and radial soundings, immediately in advance of the jetties, are likewise being made by the United States Coast Survey.

Elaborate soundings are made at least once a month, and sometimes twice per month, by my Chief Assistant Engineer, Mr. E. L. Corthell, assisted by Mr. Max E. Schmidt and Mr. W. L. Webb, civil engineers, the results of which have from time to time been promptly published by me. It would seem, therefore, that between the cost to the government and to myself and associates, the public are likely to be well informed upon the subject.

There seems to be, however, considerable discrepancy, by your statement, between the results of Major Howell's and my own soundings on the bar; and especially respecting the re-formation of the bar in advance of the jetties.

On the appearance of anonymous telegrams in the St. Louis papers sent recently from this city, stating that the water was shoaling in advance of the jetties, I authorized the emphatic declaration to be made by the South Pass Jetty Company's Secretary in that city, that this report was a 'malicious falsehood.' I say so still, although it seems less anonymous than before.

Your editorial leaves but little doubt of the fact that you have been misled by information derived from Major Howell's office. You say, "This compilation shows," among other things you mention, "that the bar has simply been pushed out, slope, shoal and all, as though it had been bodily removed from one point to another," etc. To this I have only to reply that any "compilations," or charts of soundings, showing any such result as this, are absolutely false and unreliable.

The contour lines of soundings on the outer slope of the bar embrace between the width of the jetties 1,000 feet, and these lines have frequently altered, sometimes receding on the east side of this width and advancing on the west, and again retreating and advancing on the opposite sides; and again, these lines have retreated and advanced in the middle of the jetties, leaving nearly equal depths on each side of a middle ground at their mouth. On the 25th ult. we had a channel of nearly equal depth on each side of such middle ground, while on this latter, the depth was but two or three feet less than in these channels. Last Sunday the depth in the east one was sixteen feet, and in the west sixteen and a half feet, while but thirteen feet was over the shoal between them. At no time, however, have these contour lines advanced on one part of the bar front without retreating on some other, and there has not been, and is not to-day, any average advance all over the front of the bar. At no time has any part advanced anything like so much as you assert. The eighteen feet contour line, for instance, is not to-day further seaward than it was a year ago, while the deeper contour lines have nearly all retreated; that is, have come further landward, making the outer slope of the bar steeper than ever before; while beyond the thirty feet contour line the deepening has been very decided, ranging from one to fifteen feet. I repeat, therefore, emphatically, that the reported shoaling in front of the jetties, or the re-formation of the bar on its sea slope — a phenomenon confidently predicted by Major Howell and other opposers of the jetty system — *has not occurred*, and that the effort now being made to create this belief is founded in ignorance or malice.

The cavilers at this improvement declare they have come through the jetties and found places with but ten or twelve feet on them, when we have reported fifteen or sixteen. They ignore the fact that the jetties are 1,000 feet wide, and expect to find the maximum depth from jetty to jetty, yet praise the channel maintained by the dredge boat at Southwest Pass to a degree that makes it surprising that any one should want a better one, although a deviation of thirty feet from its centre gives but fifteen feet or less, and within a distance not one quarter of the width of the jetties, there is but eight or nine feet.

The persistent misrepresentations and hostility shown by a portion of the citizens and press of this city to this enterprise, is one of the most unexpected and remarkable features developed by it. I was led to believe that every intelligent citizen of New Orleans wanted deep water at the mouth of the river. I came here with the authority of Congress to improve the shallowest one of the passes, and one not at all used for commerce, and having at high tide scarcely more than eight feet on its bar. I offered to interest the citizens of New Orleans in such pecuniary profits as I might realize by success. The plan pro-

posed had been subjected to one of the most thorough discussions and was sustained by the opinions of the very ablest engineers in the world. A very few enterprising citizens here aided me with their means, and with this aid and that supplied by myself and parties in St. Louis and New York, we have been at work less than eleven months, spending our own money, creating no interruption to the old channels of the river, and in that time we have obtained *a permanent* increase in the depth on the South Pass Bar, which is steadily improving, and which is to-day only one foot less than the dredged out groove at the Southwest Pass; and yet one would suppose from the fault-finding that we were increasing the expenses of the government, or wasting the money of all these grumblers. Whereas I have yet to hear one word of doubt or complaint from the genuine public spirited men who are spending their own money under my direction in this important work, and the noble hearted ones who are giving it a moral encouragement scarcely less potent and important.

I had not closed the reading of your editorial when I was handed the accompanying telegram from the jetties. As it is the very latest intelligence, it may possess some interest to the public. I will merely add that "average flood tide," referred to in the dispatch, is about six inches below the level of the recent tides in the Gulf of Mexico.

Very truly, etc.,

JAS. B. EADS.

"PORT EADS, May 3, 1876—6:15 P. M.

"*Mr. Jas. B. Eads:*

"From soundings taken this afternoon, I find seventeen (17) feet over the bar at average flood tide, with channel above deepening at every point.

"E. L. CORTHELL,

"Chief Assistant Engineer."

REPORT

ON THE MISSISSIPPI JETTIES.

NEW YORK, August 18, 1876.

Mr. Julius S. Walsh, President South Pass Jetty Co., St. Louis:

DEAR SIR,—I have not reported our progress at the mouth of the Mississippi at an earlier date owing to the delay in obtaining an official statement of the results of soundings made in front of the jetties about three months ago. This information will be found in the Appendix, in the letter and charts from the Superintendent of the U. S. Coast Survey to the Secretary of War. In view of the conflicting statements which have been published respecting the effects produced by our works, they will possess peculiar interest, the special points of which will be briefly referred to in another part of this paper.

Since my last report the channel between the jetties has been constantly increasing, either in width or depth, or in both, throughout its entire length of 2¼ miles.

The jetties, with the exception of a few hundred feet at their sea ends, are built up above mean low tide, and for the greater part of their length are up to the level of average high tide.

The stone covering, which will be ultimately placed over the willow mattress work now constructed, is necessary to compact and consolidate the mattresses and prevent the escape of water through their top courses. The aggregate of this escapement becomes greater as their sea ends are reached; and as the jetties are parallel, the scouring effect in the lower part of the channel is less marked than in the upper. To compensate for this loss of force, until the jetties shall have been consolidated and raised above extreme high tide, temporary wing dams about 150 feet in length have been thrown out from the jetties at short intervals towards the channel, throughout about a half mile of their sea ends. The surface width between them has thus been temporarily reduced at their lower ends to about 700 feet. The remarkably deep and wide channel already created between the jetties above this contracted portion conclusively proves the ability of the stream to maintain throughout their entire length a channel 1,000 feet wide and of the requisite depth, so soon as the jetties shall be so far completed as to entirely control the current and prevent the present waste of water. The last survey, made July 27th, shows

a channel extending down 11,800 feet from the upper end of the jetties and within only 250 feet of the deep waters of the Gulf, having an average width of about 350 feet, in which all soundings are 20 feet or more in depth. The line of deepest soundings through this length of 2¼ miles averaging at that time over 26 feet. Many soundings were over 40 feet deep. This chart will be found in Appendix (No. 4).

Some idea of the progress of the erosion going on between the jetties may be inferred from the fact that the twenty feet channel existing on the 17th of June had increased in average width nearly 100 feet throughout its entire length in the forty days between that date and the date of the last survey.

On the 14th inst. the ridge intervening between 21 feet on the river side and 21 feet on the sea side had deepened so as to give a straight and available channel entirely through the bar, 21 feet deep. This had so widened at that time, that a 20 feet channel whose minimum width was 140 feet extended entirely across the bar. See chart No. 5 in Appendix.

Believing that the public interest was concentrated wholly upon the question of our ability to successfully treat the bar in the sea, the works for this purpose were pushed with great vigor, while those required for the reduction of the shoal existing thirteen miles above, in the Mississippi River, and obstructing the entrance into the pass, were not begun so soon, nor constructed with such rapidity.

When these were commenced, a depth at mean high tide of only sixteen feet was to be found over this shoal, which was increased during the progress of our work about one foot.

Our original plan of improvement contemplated the closure of Grand Bayou. This outlet is situated midway between the upper and lower ends of the pass, and discharges 23 per cent. of its volume. Its closure would consequently add about 30 per cent. to the water passing out through the jetties, by which the current below this outlet would be largely increased, while the current in the pass above would be proportionally retarded, until the channel below the outlet should be sufficiently enlarged to restore the normal velocity. Enlargement and deepening were consequently to be anticipated below, while shoaling would be the result naturally expected above.

At the time the closure of Grand Bayou was to be made, the Cromwell steamship line were using the pass, and were furnishing indubitable evidence of the success of the jetties. The financial element of the problem made it very desirable that these vessels should not be interrupted by the anticipated shoaling, as it would give the opponents of the enterprise a plausible argument for proclaiming its failure.

The head of the pass is divided by an island into two inlets of nearly equal magnitude, and the original plan of improvement contemplated the ultimate closure of one of these. It was believed that

if Grand Bayou and one of these inlets were closed simultaneously, the expected shoaling above the pass would not occur, because, although the volume entering the pass would be temporarily lessened by the dam at Grand Bayou, the size of the entrance into the pass would be reduced in a greater ratio by the closure of one of these inlets, and the retardation of current across the shoal above the other inlet would thus be prevented. It was, therefore, determined to close the inlet and bayou at the same time. Some unavoidable delays, however, retarded the construction of the dam at the inlet until five or six weeks after the bayou was closed. During this interval the deposit, which had been feared, occurred upon the shoal, until the available depth over it was reduced to about 14 feet, and the steamers referred to were compelled to temporarily abandon the use of the pass. Since the closure of the inlet, however, the depth has been increasing, and the large steamers Knickerbocker and Hudson, of the Cromwell line, have again crossed this shoal, in going and returning through the South Pass during the last fortnight. From 20 feet on the upper side to 20 feet on the lower side of this shoal the distance is about 1,500 feet. The works in course of construction here comprise one dam 1,100 feet long, another 1,800 feet long, and a dyke 3,200 feet long—all completed above high water; also three other dykes, in the course of construction, having a total length of 2,200 feet. The most effective part of these will probably be completed within the next thirty days.

The same principle which has proved so successful at the jetties, namely, the concentration of the flowing water, forms the basis of the plan for the reduction of this shoal, and the completion of the works designed can not fail to be equally successful, while their execution is far less expensive and difficult, because they are sheltered by the river banks from the storms of the Gulf. It is possible, however, that the effect will not be as rapid as we desire, because the low-water season is approaching, and the river discharge will be diminished very considerably, by which the scouring action will be lessened.

It has been asserted in some of the public journals that the construction of the works necessary to contract the flow and deepen these obstructions must have the effect of permanently lessening the quantity of water which entered South Pass at the time our works were commenced, and would therefore cause a permanent reduction in the size of the pass. It is important to consider whether there is any cause for any apprehension of such result, inasmuch as it has been stated that it has already occurred.

Repeated measurements of the pass have been made by my assistant engineers at three different points, one about a mile below the head of the pass, one above Grand Bayou, and one below it. The result of these justifies me in declaring emphatically that there is

no cause whatever for any such apprehension. A few facts, however, which have been developed by our works will probably be more potent in removing any fears upon this point than a volume of theorizing.

The entrance into Pass a l'Outre was contracted 600 feet in width by one of our dykes, and it might reasonably be inferred that the temporary flow into the pass, being thereby greatly reduced, a permanent diminution of its size would occur. The effect of this contraction was to *raise* the surface of the water *above* our works, while *below* them the reduced supply caused the surface to be *lowered*. An increased slope was thus given to the surface of the water through this contraction. The current is caused by the surface slope of the river. Resistance to the current results mainly from the friction between the water and the bed of the stream. This frictional resistance being lessened to the extent of 600 feet, while the impelling force or surface slope was increased, a greatly increased velocity of current of course resulted, and induced rapid scouring, by which, in a few weeks, the size of the pass at the point of contraction was entirely restored by an equivalent amount of deepening. Undoubtedly while this deepening was progressing, an increased quantity of water was being thrown into the two other passes; and if this extra quantity had continued to flow into them, permanent enlargement of each would have resulted; but experience at the jetties has shown that the enlargement of channel, which occurs from an increased flow, begins at the upper end and advances down stream. This result would inevitably follow an increased flow into either of the other passes by the contraction of Pass a l'Outre; but before this enlargement of South Pass and South-west pass could extend any great distance down, the recovery by Pass a l'Outre of its full section was accomplished, and the temporarily disturbed equilibrium of the three passes was restored.

A similar result may reasonably be expected from the closure of the East inlet into South Pass.

The flow into this pass will unquestionably be temporarily lessened, and the excess will be temporarily thrown into the other passes. An enlargement of the upper ends of these passes must at once commence, but at the same time the contracted entrance into South Pass must, from the same cause, commence also to enlarge, and in proportion as the enlargement of the latter progresses, the head of water temporarily raised by the works must be lowered, and the extra flow into the other two passes must be diminished and finally cease altogether. In other words, while the river will have only half a mile in length of enlargement to make at the head of South Pass, to recover its equilibrium, it must enlarge Southwest Pass through its entire length of seventeen miles before any permanent alteration in the respective volumes flowing through the two

passes can take place. While the removal of the shoal is progressing, a considerable portion of it will be found deposited in the deep water immediately below it, where no contraction has occurred, and where the first reduction of velocity will be felt, and from whence it will be gradually removed as the enlargement above restores the velocity below.

Statements have been published creating the erroneous idea that some part of the increased depth which has been secured on the crest of the bar has resulted from the use of rakes, harrows, or scrapers. These methods were tried, in the hope of accelerating the scouring action of the current, and an apparently slight advantage, which seemed to follow the use of the first, most crude, and weaker appliances of this kind, prompted the construction of a very strong harrow and scraper combined, and the employment of a powerful tow-boat for the purpose of dragging this implement over the bar. It was worked faithfully and continuously for several days, when the depth on the crest of the bar was between 15 and 16 feet, but it was utterly useless, and the experiment was entirely abandoned. The only place where it appeared to be followed by good results was at a point about 3,000 feet above the outer ends of the jetties, where the deepening of the current was only three feet between the 4th of March and the 1st of May. This led to the belief that the channel at this part had some clay or mud lump deposit in it which yielded but slowly to the action of the current. The harrow was gauged at 19 feet, by suspending chains from the tow-boat, and was thus put at work at this place, and an increased depth of one or two feet was obtained during its working here. *Since* its use at this locality the channel has deepened six or eight feet more than the depth which existed there when it ceased working.

I desire to call your especial attention to the interesting letter of Hon. C. P. Patterson, Supt. U. S. Coast Survey, to the Hon. Secretary of War, with its accompanying charts (Nos. 6 and 7) in the Appendix.

Of the recent survey Mr. Patterson says:

"Having explained the circumstances attending the careful survey of 1875, and the partial examination of 1876—the latter being merely incidental, and not projected for comparison with the first survey, nor sufficient for such purpose—I will now, in compliance with your request, respectfully set forth the results of a comparison between the few lines of soundings run in May, 1876, and the soundings made in the same vicinity in the year 1875."

The *facts* contained in the letter and charts from Mr. Patterson are all that your stockholders or the public will be interested in, as they relate to the important and controverted question of re-formation of the bar in front of the jetties. It is proper, however, that the *value* of these facts should not be impaired by the supposition

that the last survey is not sufficiently complete to disprove the unfounded statement published on this subject, or that it was not made for the express purpose of comparison with the survey of 1875. Unless made for such comparison, it would have been without any object whatever, and would not fulfill the purpose I had in view when making the following request:

"NEW ORLEANS, March 7, 1876.

"*Hon. C. P. Patterson, Superintendent U. S. Coast Survey, Washington, D. C.:*

"DEAR SIR,—Last year Lieut Marinden made soundings on radial lines seaward from the bar of South Pass. I very much desire that these radial soundings should be repeated before Lieut. M. leaves here, and I think you will agree with me that it is important to know where the one or two million cubic yards of sandy alluvion which have been swept out of South Pass from its bar have been carried and deposited, and what changes, if any, have occurred in the contour lines off the mouth of South Pass.

"Radial lines of soundings should be made from the east and west land's ends out to two or three miles off shore.

"Hoping that you will kindly oblige me by ordering this work to be done by Lieut. M., I remain, with sentiments of high esteem,

"Yours very truly,

"JAS. B. EADS."

With reference to the incompleteness of the late survey, it should be stated that it was the intention to run out radial lines of soundings, fan-like, from the jetties to the east and west as well as centrally, but Mr. Marinden, Assistant U. S. Coast Survey, who made both surveys, was ordered, immediately after the central portion was completed, for reasons given in Mr. Patterson's letter, to stop the work. This central part consists of eleven radial lines, and is complete over the area directly in advance of the jetties, on which area any re-formation of the bar, that will obstruct the jettied channel, must occur. It is that part of the work, therefore, which is of most importance for comparison. In a space 700 yards square, immediately in front of the jetties, which is taken by the Superintendent for this purpose, there were made, in 1875, 189 soundings, and, in 1876, 157 soundings. The data of the last survey is, therefore, but little inferior to that of 1875. A greater number of soundings in the latter survey would be quite as likely to *increase* as to *diminish* Mr. Patterson's estimate of the aggregate deepening within this area.

The aggregate deepening which has occurred in this area, between the survey of 1875 and that of 1876, is stated in Mr. Patterson's letter to be 68,400 cubic yards.

In other words, within an area 2,100 feet square, immediately in front of the jetties, *which area must first be covered with deposit before a re-formation of the bar can occur*, there have been actually *excavated* out of it, and borne away by the currents of the sea and river, a mass of earth, in excess of all local deposits made on it, equal to 68,400 wagon

loads. This testimony, which, as will be hereafter seen, is confirmed by the more elaborate examinations of our own, proves that the water is *not* shoaling in advance of the jetties. It must be borne in mind that this aggregate deepening has occurred while nearly 3,000,000 cubic yards of earth have been taken up from the bar, between the jetties, by the river current, in excess of its ordinary burden of sediment, and transported over this area out into the Gulf of Mexico. If this mass had been deposited upon this area, it would have covered it to the depth of about 18 feet.

The aggregate of the 189 soundings made in 1875, is 6,410 feet, which, divided by these 189 soundings give an average depth over this area of $33\frac{9}{10}$ feet. The aggregate of 157 soundings made over the same area in 1876, is 5,594 feet, which, divided by these 157 soundings, gives an average depth over the same area of $35\frac{6}{10}$ feet, showing an average increase in depth over this area of $1\frac{7}{10}$ feet, and an aggregate deepening in excess of all depositions on it, equal to 278,000 instead of 68,400 cubic yards as stated by Mr. Patterson.

It may be said that this method of estimating the aggregate change in depth is not accurate, because the soundings in the two surveys are not exactly the same in number and location. This is true; but if they were so, the precise result thus deduced would be just as likely to exceed as to fall short of this approximation.

In the Appendix will be found a statement from the Resident Engineer, Mr. Bayley, and the Assistant Engineer, Mr. Schmidt, giving the results of a careful investigation of an area about half as large as the one in question, and embraced within its limits, but including also that portion of the outer slope of the bar originally lying between the ends of the jetties. In this area of $51\frac{7}{10}$ acres, over 600 soundings were made and instrumentally located, at about the same time the last survey by Mr. Marinden was made. The result of their comparison of this elaborate survey with that of the coast survey of 1875, shows that 206,425 cubic yards had been removed from it, which is equal to an average deepening of nearly $2\frac{1}{4}$ feet.

These corroborative facts show conclusively that Mr. Patterson has not overstated the deepening which has occurred in front of the jetties. By taking in the outer slope of the bar between the jetties, which is excluded from Mr. Patterson's comparison, the result given by him would have been largely increased. For, in this part of the outer slope of the bar, an area of about 100,000 square yards, the average deepening was then fully $4\frac{1}{2}$ feet, which would increase Mr. Patterson's estimate 150,000 cubic yards, or nearly threefold. He therefore very properly says: "It can be readily perceived that by varying the limits only a little, for instance, taking in more of the bar (which the paucity of soundings in the incomplete survey of 1876 prevented), the results, as deduced from comparison, might be materially changed."

No correct opinion can possibly be formed, as to the advance of the bar, that is based upon tbe movement of one or two contour lines of soundings in front of the jetties. For instance, it would be manifestly incorrect to claim that there has been an advance of the bar, because the 18-foot contour line had moved out 200 feet on one side, provided it should have receded 200 feet throughout an equal width on the other. The average in this illustration would show no general advance.

It would be just as incorrect to proclaim an advance of the bar on the simple fact that the 18 feet line had advanced throughout the whole width of the jetties, two, three, or five hundred feet; because a channel 21 feet deep through this line has now caused a retrograde movement of it, by which its advanced portion has receded thirteen miles up stream through the jetties and pass to the 17 feet shoal in the river above. If the average movement of the line be taken in one case, it must be in the other, and in this one it would show an enormous retrocession where none exists. The absurdity of such an assumption must be apparent from this illustration.

It is only by a careful comparison of the *aggregate* shoaling and deepening which occur from time to time within an area extending out into the deep water of the sea, and embracing that part of the outer slope of the bar and sea bottom over which the river discharges, with the condition of this area before the jetties were built, that any reliable conclusion can be reached on the question of bar advance.

That the river discharge may in the distant future cause the advance of the shoals to the west of the jetties, I have but little doubt, though the increased momentum of this discharge, by which it will now be extended much farther seaward than before, will be likely to lessen the rate of deposit upon the shoals near the jetties.

What the present generation is mostly interested in *is the area in front of the jetties, comprising the outer slope of the bar and the track of the river discharge.* As the investigations of the Coast Survey and our own examinations prove conclusively that a general *deepening* has occurred in 490,000 square yards of this area, the reported bar advance and shoaling in front of the jetties is shown to be without any real foundation.

The statement that the jetties have been extended several hundred feet, because of the advance of the bar, is incorrect. The foundation of the east jetty is yet 300 feet short of the point recommended by the Advisory Commission, and the west jetty is only at the terminus advised by that board.

As it has been stated that the small mud lump or shoal existing eight or nine hundred feet in advance of the jetties was an incipient bar caused by them, and that it has moved out 200 or 300 feet, atten-

tion is particularly called to the testimony of the Coast Survey on this subject. Mr. Patterson states that this lump was shown upon the survey prior to the building of the jetties; that the cubical contents of it above the 18 feet contour line have diminished one-half since 1875; that the water is deeper over it than before; that while the river face had receded 30 yards, its seaward face and centre had advanced but a little. Mr. E. L. Corthell, chief assistant engineer, informs me that soundings carefully made on the 14th inst., show a channel 23½ feet deep through this shoal, which is additional evidence that it is disappearing. This will be seen in the appendix on Chart No. 5, which is the latest information received from the jetties.

The favorable phenomenon of deepening immediately in front of the jetties, is one which I believe was unexpected to all the advocates of this system. It is, no doubt, caused by the sea current which is induced by the winds prevailing in this locality. These blow almost constantly from between the northeast and southeast. The current which results from them is driven westwardly beneath the river discharge, and excavates more room for itself as the volume from the jetties becomes gradually stronger.

I have differed on this question, I believe, from all engineers who have expressed views upon the subject. I have constantly maintained the more extreme opinion that the necessity for extending the jetties after a depth of 30 feet shall have been secured by them, will not occur for many centuries. The present deepening in advance of them strengthens my belief upon this point.

The U. S. Commission, which recommended the application of this system, anticipated that there would be an advance of the bar, and made an estimate to cover the probable cost of extending the jetties to keep pace with it. Therefore, even if an advance had already occurred, it would be no evidence that they would not completely fulfill their purpose.

In seventeen months after the passage of the act, and within fourteen months from the commencement of the work, the jetties have solved the problem presented at the mouth of the river. In their unfinished condition they have withstood, with but trifling injury, two very severe storms, one surpassing in violence any known in that locality for many years; they have demonstrated the entire ability of the delta formation to safely sustain the works necessary to control the river discharge; they have not been overturned by mud lumps, nor swallowed up in quicksands, nor undermined by the river current; and although largely over 3,000,000 cubic yards of earth have been swept out from between them into the Gulf, and the channel across the bar has been deepened from eight or nine to twenty-one feet, no evidences of a re-formation of the bar have

yet occurred to justify the belief that any extension of them will be necessary.

I have the honor to be,

Your obedient servant,

JAMES B. EADS,

Chief Engineer, South Pass Jetty Works.

APPENDIX.

LETTER OF HON. C. P. PATTERSON, SUPERINTENDENT U. S. COAST SURVEY, TO HON. J. D. CAMERON, SECRETARY OF WAR.

U. S. COAST SURVEY OFFICE,
WASHINGTON, August 1, 1876.

SIR,—I have the honor to acknowledge the receipt of your letter of July 19th, requesting to be furnished with a comparative chart of soundings recently made in front of the South Pass bar in the Gulf of Mexico, "and a statement setting forth what amount of shoaling or deposit has occurred since the survey made by you last year in advance of the jetties; or what amount of deepening, if any, with the view of determining what amount of advance had been made at the time of your last survey by the South Pass bar in front of the jetties since their construction."

In reply I would respectfully state that the law providing for a special survey of the South Pass of the Mississippi River, Statutes at Large, Second Session, Forty-Third Congress, p. 465, is as follows:

"That in order to facilitate the proper location of said jetties, which shall not be less than seven hundred feet apart, and to correctly determine such effects as may be produced by them, the Chief of the Coast Survey shall, as soon as practicable, cause a careful topographic and hydrographic survey to be made of said pass and bar, and shall submit the same to the Secretary of War, who shall furnish to said Eads the results of any such survey. And the sum of five thousand dollars is hereby appropriated out of any money in the Treasury not otherwise appropriated, for said survey and examination."

This law was promptly complied with. I directed the survey, and the work was executed in May and June, 1875. The orders of the President of the United States relative to the grant for the construction of jetties at South Pass, of date July 27th, 1875, were issued from the War Department August 5, 1875, as "*General Order No. 75*," and by the import of paragraph 1, all strictly legal connection

between the Coast Survey and surveys relative to the South Pass constructions, ceased at that date. In the following winter the regular work of the Coast Survey was resumed at the delta, and before the party left the section of work, Mr. Eads requested the aid of the observer for repeating the small part of the work done in the special survey, and tendered the use of a steam launch. With my consent the observer was thus occupied on two days, April 29 and May 15, 1876, but was recalled in consideration of the general impropriety of permitting continuous work, not only without authority of law, but in seeming rivalry with the officer of engineers who had been detailed by the Hon. Secretary of War for inspecting the progress and quality of the constructions, and the effect of the projected improvement of the South Pass.

Having explained the circumstances attending the careful survey of 1875, and the partial examination of 1876—the latter being merely incidental, and not projected for comparison with the first survey, nor sufficient for such purpose—I will now, in compliance with your request, respectfully set forth the results of a comparison between the few lines of soundings run in May, 1876, and the soundings made in the same vicinity in the year 1875.

Accompanying this letter are a comparative tracing and four special tracings of the space covered by both the first completed survey and the second or unaccompanied survey.

The special *Tracing No. 1* gives all soundings made within its limits in May and June, 1875, which limits define ths area of the partial examination of April 29 and May 15, 1876. The space is divided into squares with sides of 100 yards. Equal depths are indicated by broken lines — one to three fathoms in blue, three to six fathoms in red, and six to nine fathoms in green.

On *Tracing No. 2* the partial survey of 1876 is treated in the same manner, but with full lines indicating equal depth. The incompleteness of this survey and paucity of soundings, especially on the seaward face of the bar, is quite evident.

A careful study of both tracings shows that no reliable result as to changes can be obtained by a computation of the volume of water superincumbent within the limits given at the time of each survey on account of the great irregularity of the bottom, and want of data sufficient for such calculations. Such comparison (with the means now at hand) can furnish only average results. Hence resort was had to ascertaining approximate differences of depth for integral parts within the limits of the survey, by interpolation and graphical construction with the approximate results shown by *Tracing No. 3*.

On that the surface shaded *black* shows where the water has shoaled, and the part shaded *red* shows where it has deepened between June, 1875, and May, 1876. The figures show the amount of

change in corresponding colors, and the curves express changes in 6 feet differences of level.

The greatest amount of shoaling appears to have taken place on the seaward slope of the bar and of the shoals beyond, while the most scooping out occurred on the upper or river face of the shoals.

The lines of soundings run in 1876 were so few on the seaward face of the bar, that only general results can be had in the comparison; as on only two of the lines can any comparison be made. A line run in 1876, about 50 yards eastward from the western jetty, shows that along it the bar has advanced in a southeasterly direction about 80 yards by the 18 feet curve; 55 yards by the 24 feet curve, and 45 yards by the 30 feet curve.

A line of soundings running about 90 yards distant from, and westward of the eastern jetty, shows a much smaller change, namely: about 12 yards advance in the 18 feet curve, and 5 yards in the 24 feet curve. The foot of the slope in 29 feet depth in the survey of 1875, appears to be identical in position with a depth on one of the lines run in 1876 of 30¾ feet. The bottom within the space enclosed between these two lines shows great irregularity by the survey of 1875; and as it was crossed by only one line of soundings in 1876, no evidence is furnished in regard to changes in the outer slope of the bar, midway between the jetties.

The survey of 1875, as well as soundings made in 1876, show a shoal about 300 yards seaward of the bar. Comparing approximately (for the data is not sufficient for accurate conclusions), it is perceived that within the 18 feet curve this shoal had become narrower by about 30 yards and longer by about 40 yards, and that while the river face had receded 80 yards, its seaward face and centre had advanced but a little. The least depth on this shoal in 1875 was 12 feet, and the depth found in 1876 was 14½ feet, but in the soundings of this year the least depth may not have been found. The area enclosed by the 18 feet curve in the survey of 1875 amounts to 8,600 square yards, and in 1876 to about 7,000; and the contents of the shoal above 18 feet was, in 1875, equal to 8,000 cubic yards, and in 1876 to about 3,700 cubic yards, or the shoal above 18 feet had decreased about one-half.

Taking the space marked A, B, C, D, on Tracing No. 3, being a square of 700 yards (or 490,000 square yards) directly in front of the bar, 216,500 square yards have decreased in depth and 273,500 square yards had increased in depth. The deposits within the same boundaries, according to the results given for convenient limits on *Tracing* No. 4 amount approximately to 311,300 cubic yards, and the scouring to 379,700 cubic yards, a difference of 68,400 cubic yards, equal to a space of about 410 by 41 yards, and 4 yards deep.

It can be readily perceived that by varying the limits only a little, for instance, taking in more of the bar (which the paucity of sound-

ings in the incomplete survey of 1876 prevented), the results, as deduced from comparison, might be materially changed.

I have the honor to be,

Very respectfully yours,

(Signed) C. P. PATTERSON,
Sup. U. S. Coast Survey.

Hon. J. D. CAMERON,
Secretary of War,
Washington, D. C.

NEW ORLEANS, June 13, 1876.

Jas. B. Eads, Esq., Chief Engineer, New Orleans, La.:

DEAR SIR: Herewith I submit to you a copy of a communication received from Assistant Engineer Max E. Schmidt, in relation to what has occurred at the jettied mouth of South Pass.

Since its receipt I have examined his data and calculations, and find them to be reliable and correct. I have compared the chart of 1875 with that made from our recent and careful soundings over the same area, and there can be no doubt of their identity as to location.

I am, very respectfully,

Your obd't serv't,

(Signed) G. W. R. BAYLEY,
Resident Engineer.

SOUTH PASS JETTY WORKS, ENGINEER'S OFFICE,
Port Eads, La., June 5, 1876.

G. W. R. Bayley, Esq., Resident Engineer, 22 Common street, New Orleans.

Dear Sir—At the request of Captain Eads I have made a very careful examination of the present condition of the Gulf bottom, directly in front of the jetty ends, in order to determine the effect produced by our works beyond the original crest of the bar.

I have taken numerous soundings, beginning at a line across the jetties 11,000 feet from the eastern "Land's End," where the old crest of the "Bar" is located, as shown on the U. S. Coast Survey Map of 1875.

I have assumed this to be the crest of the bar at that time, because the water there began to deepen; according to that map, the 18 feet contour line being about 900 feet beyond it. Below this line I have made about six hundred soundings over an area of 51.7 acres, enclosed within the jetty lines and lines tangent to them extending beyond the jetties, 1,000 feet apart, to the distance of 2,000 feet seawards from the initial line, and from thence 730 feet further in straight lines converging to a central point of intersection, which is

in latitude 28 deg. 59 min. 07.4 sec., and longitude 89 deg. 08 min. 04.3 sec. All of my soundings were located by instrumental observations from main triangulation stations of the U. S. Coast Survey, and afterwards plotted with great care. The chart of the U. S. Coast Survey of May, 1875, was then placed underneath a tracing of our plotted soundings, and the computations were based upon parallel longitudinal sections, 50 feet apart, commencing at the old crest of the bar and extending as far out as the area enclosed.

This investigation shows that the volume of water which covered the Gulf bottom within this 51.7 acres beyond the old crest of the bar in May, 1875, to the level of mean high tide, was 1,970,849 cubic yards, while our recent soundings show that it is now covered with 2,177,274 cubic yards, thus giving a gain of 206,425 cubic yards of water. This is equivalent to an average increase in depth of nearly $2\frac{1}{2}$ feet ($2\frac{47}{100}$ ft.) all over an area of Gulf bottom extending out 2,730 feet beyond the old bar crest and in front of the jetties.

I am, sir, very respectfully, your obedient servant,

(Signed) MAX E. SCHMIDT,
Assistant Engineer South Pass Jetty Works.

LETTER

TO HON. W. S. HOLMAN, CHAIRMAN COMMITTEE ON APPROPRIATIONS, HOUSE OF REPRESENTATIVES.

WASHINGTON, D. C., Jan. 29, 1877.

Hon. W. S. Holman, Chairman of Committee on Appropriations, House of Representatives:

DEAR SIR,—I am told that it was currently reported on the floor of the House last Saturday that I had expressed to the Hon. Secretary of the Treasury a willingness to accept the payment of $500,000, now due me, in money instead of bonds. I desire to give this statement the most emphatic denial. I felt so intensely the injustice of the reference of the matter to Congress that at my first interview with him I expressed myself with such warmth as to call from him a re-

proof, which made me conscious that unintentionally I had given offense, for which I promptly apologized. At this brief interview I assured him I had payments to make in the early part of February of such magnitude as to bring upon me almost certain financial dishonor if I did not receive this payment immediately. The only comforting assurance I received in reply was that he would issue the bonds unless Congress appropriated the money promptly. My two subsequent interviews with him were exceedingly brief, and were spent in the vain effort to induce him to name some definite day when he would give me the bonds if the action of Congress was not prompt. But I had no idea of waiving my right to the bonds by insisting on a day being named when he would give them to me upon his own construction of the law.

I cannot view the reference of this matter to Congress as anything other than unjust, oppressive, and directly contrary to the law, and the intention of, and plain understanding with, the Senate and House committees of the 43d Congress, which prepared the act.

That the present Congress and the country may be fully advised of my reasons for this belief, and be able to form a correct judgment of the matter, I will state some facts not publicly known, but some of which at least would have been given to the House had not debate been terminated by the "previous question" being moved. Mr. Conger stated to your committee that he was charged by the committee on commerce with the preparation of the bill; that he was in favor of the canal plan, and had spoken against the jetty bill when the measure first came up. He stated to the House on Saturday that the committee had framed the law to bind me "as if in a vise," to avoid the possibility of my drawing a dollar from the government not absolutely my due. He was the author of some of the severest conditions in the law, conditions that have delayed my right to this first payment at least four months. His testimony in my behalf is therefore valuable, and it is proper it should be known that he stated to your committee last week, that if the clause directing the Secretary of the Treasury to issue me the bonds, in just such contingency as this, is not full and clear, the committee on commerce had failed to express their intention.

He could have stated with equal truth that the committee when framing the bill desired to avoid appropriating the money for the work at that time, and that the mandatory clause, directing the Secretary of the Treasury to issue the bonds, was put in with the sole purpose to save me absolutely from any reference whatever to Congress, in the matter of pay when earned; and that this was done for cogent reasons, urged by me, and based upon personal experience of the indisposition of legislative bodies to act justly or even promptly in the payment of claims. Members of both committees fully understood this at the time, and conceded the propriety of securing,

beyond cavil, absolute promptness in the matter of payment. Many of them knew that a commission, authorized by Congress, had declared eight years previously that I was entitled to over $59,000, it being a balace due me on two of the twenty-two iron-clad vessels which I had built for the United States, and that that amount was still due me, because I had not the right to sue for it in court, and would not subject myself to the delays and humiliation which claimants are liable to, when pressing their claims before Congress.

Members of the committee knew that I had had other expensive experience which had taught me that it would have been not only an unwise hazarding of my own means, but an inexcusable jeopardizing of the money confided by my associates, to have undertaken this great work without a clear and positive understanding that my payments should not require any action whatever by Congress *after* they respectively became due.

I refer to these personal matters with regret, and with all due respect to yourself and to the Senate and House of Representatives. I mention them only because of my conviction that a proper respect for the opinions of my fellow citizens and justice to myself and associates demand that the reasons which led me to insist on having my payments absolutely certain, without further action of Congress, and the fact that those reasons were well known to many members of those committees, should, in this juncture be made public.

In reference to my right to the bonds, I submit that the language of the act puts it beyond controversy. The words are as follows:

"That the option of discharging the obligations herein assumed by the United States either in money or bonds is expressly reserved; and the Secretary of the Treasury is hereby directed to issue the bonds of the United States, bearing five per centum interest, of the character and description set out in the act entitled 'An act to authorize the refunding of the public debt,' approved July 14, 1870, to said Eads or his legal representatives, in payment at par of the aforesaid warrants of the Secretary of War, unless the Congress of the United States shall have previously provided for the payment of the same by the necessary appropriations of money."

On the 19th of January the Honorable Secretary of War drew his warrant or requisition on the Treasury Department, in my favor for $500,000. On the 20th I presented this requisition, and Congress not having "previously provided for the payment of the same by the necessary appropriations of money," my right to the bonds had, by the express terms of the act, become a vested right.

That this is exactly what was intended by both committees in framing the act, the members of those committees will assure you. I had proposed to do what was regared by almost everybody as so impracticable that I was only permitted to make the attempt upon the terms of "no cure, no pay," although it involved a certain outlay of more than a million dollars, and possibly two millions, before any

compensation whatever could be received. Therefore every consideration of fairness required prompt payment for the successful performance of such an undertaking, and to secure this Congress stipulated that bonds should be issued to me at once, if the proper appropriations, when the warrant of the Secretary of War was presented for payment, had not then been made.

It does not affect the justice of my claim for the bonds that the government has the money in the Treasury, and that Congress might have appropriated it in time, if it had acted on the information given to your committee more than sixty days ago, through the annual report of the Secretary of War, that the payment would be required on or before the 1st of February. The width and depth of channel entitling me to this payment were officially reported nearly five weeks ago from the jetties, and were certified to the Secretary of War on the 9th of this month, and I have been three weeks in sight of the Treasury Department, waiting to get the amount now due me. Last October this depth and width of channel were already secured. That it was not then officially measured by the inspecting officer of the government was because that officer held that an equal width and depth were required at the head of the pass to entitle me to a payment.

This question was at my request submitted by the Secretary of War to a commission of three of the most eminent engineers in the army, each one of whom was opposed to Congress conferring upon me, or any other private citizen, the concession under which I am acting. The unanimous report of this commission proves that the inspecting officer was wrong in his construction of the law. The Secretary of War, while agreeing with this interpretation, declined to give me the warrant on the treasury until the commission's view was submitted to, and approved by the Attorney-General. Thus nearly four months have really elapsed since the present payment was honestly and fairly earned. It requires but a simple calculation to show that 10 per cent. interest for four months on $500,000 amounts to over $16,000; yet the payment that was really earned at that time, if it had been promptly paid according to the spirit of the law, would have saved me in interest alone, much more than $16,000. It would, besides, have enabled me to construct works costing ten times that sum, under the most favorable conditions of extreme low water. I am advised by telegraph this morning that the river is already rising rapidly at New Orleans, and I have the certain knowledge that the cost of this delayed work will be fully double, when executed, as it now must be, during the flood stage of the river.

That the bonds are worth a premium, no matter how large, does not affect my right to them. If the premium were sufficient to make good the loss I have already suffered from the government's delay, and this premium had to be paid by the United States, instead of by

the capitalists who buy the bonds, it would be but fair even then for such loss to fall on the government.

The honorable Secretary of the Treasury, in his letter of the 24th to you, gives the following reasons for recommending payment in money:

"It is submitted that to issue the bonds provided for in the act would be unwise, as it would, without actual public necessity, or lack of public revenue, increase the public debt, and, in this instance, operate a direct loss, as a financial operation, to the government of some $60,000, these bonds being at this date at a premium of 12¾ per cent."

This proposition is as unsound as is the construction of the law by which it is claimed that a subsequent appropriation of money can be justly applied to meet a payment which the law declares shall be made in bonds unless the money shall have been previously appropriated. The predicted loss in this case is entirely fallacious. The government does not pay the $60,000 premium; that is paid by those who buy them. Hence, as it is not proposed to issue and sell them so as to pay me from the proceeds, the government can neither make nor save the $60,000.

Nor does the issue of them to me necessarily increase the public debt, as the $500,000 of money will remain in the treasury, and may be used to retire that amount of the eight hundred and fifty-six millions of 5 and 6 per cent. bonds outstanding on 30th December, 1876, and now redeemable at par. If the money be paid to me, the ability of the gevernment to pay off and stop the interest on $500,000 of 5 per cent. bonds now outstanding is lessened to that extent.

There is one way, and one only, by which the government can make this $60,000 premium, but it involves the unwise course the Secretary objects to. Congress can authorize him to issue the half million bonds provided for in the act, sell them to the highest bidder, pay my requisition on him with a part of the proceeds, and put the remainder in the treasury. This is the only way for the government to make the transaction profitable. This plan will in no wise more directly conflict with the law (although that declares that the Secretary shall issue the bonds "to said Eads in payment at par of the aforesaid warrants of the Secretary of War") than appropriating money now in the treasury subsequently to the presentation of the warrant, while it would be a financial success.

It is urged that because the Secretary of War informed Congress that this payment would probably be due on or before the 1st of February, therefore it may be paid to me in money any time before the first of February.

The law declares "that the Secretary of War be, and he is hereby authorized and directed to carry into effect the provisions of this act on behalf of the United States." He, therefore, represents the

United States and not me; and even if he failed to specify to Congress the exact time when any of my payments would become due, it would be manifestly unjust for the government to delay them, and thus take advantage of the neglect or error of its own agent.

The government unquestionably has the option, before payment becomes due, to pay in bonds or money. Unless there be a time when that option terminates, I might be compelled to wait indefinitely for an appropriation of money. If the word "previously" does not refer to the time when the warrant of the Secretary of War is presented, it has no reference to any time whatever; and if the appropriation with which the warrant is to be paid, can be made *subsequently* to its presentation, the word *previously* is absolutely without meaning.

In the honest conviction that a great injustice will be done to myself and associates by the passage of the bill proposed by your committee, I have the honor to be

Your obedient servant,

JAS. B. EADS.

LETTER

TO THE SECRETARY OF WAR.

NEW ORLEANS, April, 19, 1877.

Hon. George W. M'Crary, Secretary of War, Washington D. C.:

SIR,— On the 7th of February, 1877, I addressed a letter to Hon. J. D. Cameron, Secretary of War, requesting that Capt. Brown, U. S. Engineers, assistant of Gen. Comstock, stationed here, be instructed to furnish me or my chief assistant engineer at the jetties, the results of his soundings and current observations in the channel through South Pass. I said that permission for one of my assistant engineers to copy his charts would be sufficient for my purpose, and would thus avoid any possible increase of expense in his office.

This letter was written because my chief assistant had been refused a copy of a survey of the shoal at the head of the Pass, just completed by Capt. Brown, and which I desired him to obtain and send to me in Washington. Nearly a year ago (23d May, 1876) I requested of the Hon. Alonzo Taft, Secretary of War, "that instructions be

issued to the inspecting officer * * to promptly supply me with any official information he may from time to time acquire respecting these works and their results, which I may deem important to facilitate us in carrying out the intent of the grant, or in protecting us from misrepresentation." In compliance with this request the Secretary addressed Gen. Comstock letters, dated 28th June and 31st July, 1876, which directed him to forward me a duplicate copy of his official reports simultaneously with the transmission of the originals to him, and to furnish me "the results of actual soundings that have been or may be hereafter made under (his) direction, in connection with this improvement." In compliance therewith, instructions were given, I believe, by Gen. Comstock to Capt. Brown, to permit me and my assistants to *look* at the results of his soundings, but not to permit me to take any copies of them without first referring them to him at Detroit.

It is scarcely necessary for me to point out the importance of having the earliest official information respecting any changes which are produced by my works; and I respectfully submit that there can be no injury to the public by furnishing me promptly any such information as soon as it is obtained by Capt. Brown.

I do not ask that he should make surveys or observations, or perform any work for my benefit or information; but as these are contemplated by the law, and are made for your information, and for the benefit of the public, I can not conceive how it is possible that the public interest can suffer, or the dignity of the Secretary of War be lessened, by permitting me to know, at the earliest moment, whatever facts are developed by these surveys, that have relation to the success of the improvement.

Until the instructions of June and July referred to were issued to the inspecting officer, the results of the surveys of his assistant were carefully kept secret from me and my employees; and it was not until after they were transmitted by Capt. Brown to Gen. Comstock at Detroit, and by him to the Chief of Engineers, and by him to the Secretary of War, and by him to Congress, and by Congress to the public printer, and by him back to Congress, that they were seen by the public or myself. They were then so old as to be of little interest or value to any one.

Although the instructions of the Secretary of War were evidently intended to give to me the benefit of this information at the earliest moment, I can not at present have a tracing from Capt. Brown's official surveys made, even at my own expense, until it is sent to Detroit for examination or approval. The location of an inspecting officer on the Northern Lakes for works of such importance at the mouth of the Mississippi, and the difficulty of obtaining a statement of the simplest facts from him with promptitude, is an injustice to me and my associates, and an injury to the public.

The depth and width of channel between the jetties last October entitled me to the first payment of $500,000 on account of this work. The Secretary of War ordered Gen. Comstock to come to Washington for the purpose of consulting him with reference to my obligations respecting the shoal in the Mississippi River at the head of the pass. Gen. Comstock was emphatic in the opinion that I was not entitled to the payment, because I had not an equal width and depth through this shoal. I appealed from this decision, and the question was referred by the Secretary of War to a commission of officers of higher rank, viz: Generals Barnard, Wright and Alexander. They decided that I was entitled to this payment whenever the requisite width and depth were secured through the jetties, without reference to the depth on the shoal; the depth through the latter being insured by my liability to have the grant forfeited. This opinion was then submitted to the Attorney General, who emphatically sustained it, thus proving that Gen. Comstock was wrong. The result, however, caused me to be delayed several months in receiving the payment to which I was entitled in October, and it was not until about the middle of February that I received it.

After suffering the hardship of delay in payment, resulting from the inspecting officer misinterpreting the law, and awaiting its reversal by the late commission and the Attorney General, I was put to a further delay in payment; because, although this survey, like all others made since Capt. Brown was stationed here in December, 1875, was not made under the formal supervision of the inspecting officer, yet it had to go to Detroit for examination and approval by him, and then, after the chart reached there, some informality in its certification at the jetties necessitated a further delay until a duplicate could be sent from the mouth of the Mississippi to Detroit, after which the report entitling me to payment was finally sent by the inspecting officer to the Secretary of War.

Within the last week I have found it necessary to provide an additional amount of money to carry on these works, and I submitted the terms of a loan for $200,000 to capitalists in this city, who had previously supplied a portion of the money expended on them. A meeting of these gentlemen was called a few days ago, at which the loan was proposed. The next morning the Associated Press dispatches contained a synopsis of Gen. Comstock's report of 5th April to you, in which it is stated that the 20 feet channel through the jetties had been reduced from 200 feet to 70 feet in width. The effect of this upon the loan you can readily understand.

The report just made to you, dated 5th April, 1877, gives the result of soundings made a month previously; but it gives neither to you nor to the public any information as to the present condition of the channel. A subsequent survey or reconnoissance made by Capt. Brown, I am verbally informed by him, within the last ten days,

shows a 20 feet channel, with a least width of 300 feet, yet Capt. Brown dare not certify this improvement to me, because he has no authority or permission from Detroit to do so.

The delay in getting my first payment prevented me from completing and strengthening the sea ends of the jetties to resist the storms of winter; and I have been compelled to rebuild a large amount of the work, the destruction of which caused the deterioration of channel referred to by Gen. Comstock. Their improved condition has now again enlarged the channel; but before I can get the official evidence of it, its certification will be of no value to me.

Last May, when semi-official misrepresentations were published by Capt. Howell, respecting the depth of channel we had then secured through the jetties, I asked the Secretary of War, by telegraph (see my letter, 23d May, 1876), to direct Gen. Comstock, who was then on the spot, to measure the depth between the jetties, and certify the same, so that I could correct this misrepresentation, which was then seriously embarrassing our enterprise by destroying the confidence of the public and the faith of capitalists in it. This could have been done in three hours, but the request was refused, and nothing but the passage of the Cromwell steamers through the jetties, a few days afterwards, furnished to the public the evidence that Capt. Howell had officially published a deliberate and gross misstatement of the depth of the jetty channel. In connection with this misstatement, the same officer, at the same time, published a statement to the effect that, from his own surveys, he knew that a bar was forming 1,000 feet in advance of the jetties, and that a shoal had made out 380 feet from the west jetty towards this bar. This statement *was absolutely untrue.* It was designed to impress the public with the belief that these works would prove a failure, as the rapid re-formation of the bar in advance of the jetties, predicted by the Chief of Engineers, was actually progressing; whereas, I knew from my own surveys and from soundings just then made by the U. S. Coast Survey, in front of the jetties, that the very reverse of his statement was the fact. An immediate official disproof of Capt. Howell's statement regarding the depth of channel being denied me (see Mr. Secretary Taft's telegram in my letter of 23d May), I appealed, by telegraph, to the Superintendent of the Coast Survey to instruct Mr. Marinden to certify to me the results of the survey he had just made, and to make which survey *I had furnished a steamer.* His refusal will be found in my letter of 23d May. I was, however, determined to have this official disproof if possible, and therefore requested the Secretary of War to obtain it. On the 19th of July, he requested the Superintendent to furnish the *War Department* with a comparative chart of the soundings made May, 1875, and May, 1876, in front of the jetties. The verbal declaration after receipt of this request, made to me by the Superintendent that *he would not* supply

this information, even to the War Department, caused me to appeal by letter a few days afterwards to Mr. Secretary Morrill, of the Treasury, to instruct the superintendent to furnish the chart to me, with an official statement of the results shown by it. Mr. Morrill, on 26th July, refused this request, on the plea that the last survey was "unauthorized and informal;" "while provision is made in the said [Jetty] act for the facts and information desired through the War Department."

Being thus foiled in getting the official disproof of this misrepresentation of Capt. Howell, I finally appealed to the House of Representatives, and a resolution, directing the Secretary of the Treasury to furnish the House the specific information asked for by me, was unanimously passed by that body, immediately after the Secretary of the Treasury refused to give it to me. In pursuance of this resolution, the House and the War Department were supplied 1st August with the information solicited a fortnight previously by the Secretary of War, and it proved that, instead of a re-formation of the bar, 68,400 cubic yards of material had actually been scoured away, in a space 2,100 feet square, immediately in front of the jetties, in excess of all deposits made on that area.

I refer to these facts regretfully, and only to show you that when official information would be of value to me, or even when absolutely necessary to right a gross wrong by a government officer, it has been almost impossible for me to get it. Although the fact was shown by two surveys, and the report of the Superintendent of the Coast Survey last August, that the predicted bar advance had not occurred, but that the water last May was actually deeper immediately in advance of the jetties than when they were commenced; and although this fact would greatly increase the confidence of the public in the permanency of this improvement, and although it constitutes a most interesting fact in the history of the work, it has not yet elicited the notice of the inspecting officer in his reports to you. Every temporary *advance* of the contour curves of the bar, however, observed during the rapid scour between the jetties previously, was reported by him, but his reports have never alluded to the fact that a decided recession of the outer face of the bar has occurred since the construction of the jetties.

I earnestly beg that, in connection with these representations, you will kindly consider the fact, that we are executing a great national work, almost wholly without aid of the government—for thus far we have received less than one-tenth part of the price to be paid for it—while we have already secured much deeper water than ever existed at the mouth of the river before, and which now constitutes a safe channel, in no place less than 20½ feet deep, at average high tide, from New Orleans to the Gulf, where there was previously scarcely 8 feet in depth. Our works and our good faith surely entitle us to such

aid as the government can give us without injury to the public interest, and also to such moral support as can be rendered by furnishing promptly, in an official form, any certification that may be desired respecting the results accomplished. The law constitutes you the agent of the United States to carry into effect the provisions of the act, and your practical knowledge will certainly plead my excuse for appealing to you most earnestly, to correct the injustice we are suffering, more especially as it has been continued so long after a correction has been solicited. If you will kindly consider that this work is not only the largest, in point of cost, which the United States is executing, but that it far surpasses, in the importance of its results, all others in this country, you will, I am sure, pardon me for trespassing upon your time with a letter of this length.

In conclusion, I respectfully beg:

1st. That the inspecting officer of these works be located at New Orleans, or at the jetties; and,

2d. That he be authorized to publish promptly, from time to time, the depth and width of channel through South Pass; and,

3d. That he be directed to furnish me or my principal assistant engineer, officially and promptly, such information respecting the changes in the channel throughout the pass, the jetties, and the outer slope of the bar, and such other results of the works in progress as he and his assistants shall obtain, from time to time, by their surveys and observations.

I have the honor to be your obedient servant,

JAS. B. EADS.

LETTER

TO THE SECRETARY OF WAR, SUBMITTING A STATEMENT RELATIVE TO WORKS AT THE SOUTH PASS OF THE MISSISSIPPI RIVER.

WASHINGTON, D. C., May 7, 1878.

SIR,—I have reached a point in the construction of the works authorized by the jetty act at which I deem it absolutely necessary to communicate certain matters for your consideration. I respectfully submit, therefore, the reasons which induce me to ask for such modification in the times of payment set forth in the law as are necessary to re-

lieve me and my associates of the serious financial difficlties with which we are embarrassed, and to enable us to prosecute the work with greater energy.

The progress of the work has shown that the desire to guard the government against the possibility of bearing any portion of the risk of the jetty system, or of the hazards of construction, has resulted in framing a law which imposes on us unnecessarily stringent conditions of payment. In consequence of the very large portion of the work which we have had to execute in order to secure the two payments already received, and of the stringency of these conditions, we find ourselves oppressed with such a burden of debt as to almost completely paralyze, for the present, our ability to push the work with the energy necessary to insure the largest benefits to the public at the earliest possible time.

The provisions of the law were intended to afford a reasonable reimbursement of our outlays as fast as the work progressed, after certain specified depths of channel should be secured by permanent works. It was impossible, however, to tell with any degree of accuracy how much of the whole work would have to be executed before we could be entitled to the first payments under the law, and while the total cost of the improvement will not exceed the original estimates, the proportion of the entire outlay necessarily expended to secure the present depth has greatly exceeded our expectations.

Experience has shown, and custom has sanctioned the wisdom of the government paying 90 per cent. of the contract price for work as it progresses, by which those who undertake it may avoid excessive rates of interest and needless financial burdens, which can result in no benefit to the government.

The compensation fixed in the law for the work we are executing is to be $5,250,000. We have already completed at least 80 per cent. of this entire work, and have received on it thus far only $1,000,000. If we were compensated for 90 per cent. of the work done, we would receive $2,826,000 more than has been paid to us. We do not ask for any such liberality, but refer to this fact to show the hardships under which we are laboring by the terms of the law, and the absolute security with which the government can grant the relief we are compelled to ask.

By the terms of the act, thirty months from its approval were allowed within which to secure a depth of 20 feet, and two feet additional are required to be secured each year thereafter. The act was approved March 3, 1875, and by September 3, 1877, we were required to have a channel of 20 feet, and 22 feet by September 3, 1878. These depths have been already secured, and the stipulated compensation received. We have, therefore, by the terms of the law, until September 3, 1879, to secure 24 feet, and to September 3, 1880, to secure the 26 feet channel. The interests of the public will

of course be promoted by the attainment of these depths at an earlier day.

Under the present terms of payment it will be impossible for us to expend upon the work the large additional sums still necessary to secure the maximum channel at the earliest possible period, for the reason that the indebtedness already incurred will absorb so much of the next payment as to leave for it a totally inadequate provision.

The sum of $1,250,000 of the stipulated compensation becomes due and payable after certain depths have been maintained for twelve months, and these payments bear interest at the rate of 5 per cent. per annum. By adding these deferred payments to the cash payments as the latter are earned, the government will save interest on the respective amounts, and will greatly relieve us, while an earlier completion of the work will be secured.

The Commission of Engineers authorized by Congress in 1874, and which reported in favor of applying the jetty system to the South Pass, proposed to secure a channel 30 feet in depth, and the permanent maintenance of only 25 feet, without any specified width. The jetty act requires a permanent depth of 30 feet with a least width of 350 feet. This great width of 30 feet depth will involve a much larger channel than was contemplated by the Commission as proper for the size of the pass. Such great width cannot probably be secured without a central depth of channel several feet greater than that recommended by the Commission. We do not ask to have the depth of 30 feet lessened, but observation confirms the opinion (which I expressed to the committees when the bill was under consideration), that the width required was injudicious and might involve injury to the works.

The payments under the present law are as follows:

On securing—			
24 feet deep by 250 feet in width	$500,000;	cash in one year	$250,000
26 feet deep by 300 feet in width	500,000;	cash in one year	250,000
28 feet deep by 300 feet in width	500,000;	cash in one year	250,000
30 feet deep by 350 feet in width	500,000;	cash in one year	500,000
Total	$2,000,000	Total	$1,250,000

The amendments desired are as follows:

On securing a channel through the jetties—	
24 feet deep by a least width of 150 feet	$750,000
25 feet deep by a least width of 150 feet	750,000
26 feet deep by a least width of 150 feet	500,000
27 feet deep by a least width of 100 feet	375,000
28 feet deep by a least width of 100 feet	375,000
29 feet deep by a least width of 100 feet	250,000
30 feet deep by a least width of 100 feet	250,000
Total	$3,250,000

Provided, that when each of the above depths and widths has been obtained the survey shall also show through the jetties a channel of the following depths and widths, viz: When 24 by 150 feet shall have been obtained, there must also be a channel 22 feet deep by a width of 200 feet; when 25 by 150 feet shall have been obtained, there must also be a channel 22 feet deep by 250 feet wide; when 26 by 150 feet shall have been obtained, there must also be a channel 22 feet deep by 300 feet wide; when 27 by 100 feet shall have been obtained, there must also be a channel 24 feet deep by 200 feet wide; when 28 by 100 feet shall have been obtained, there must also be a channel 24 feet deep by 250 feet wide; when 29 by 100 feet shall have been obtained, there must also be a channel 24 feet deep by 250 feet wide; when 30 by 100 feet shall have been obtained, there must also be a channel 26 feet deep by 200 feet wide.

By the above arrangement, the first payment of $750,000 will not be made until a channel is attained large enough for all practical purposes; and the fact that no further payments are to be made, except as each additional foot in depth is gained, insures every effort to maintain and increase the size of the channel as fully as under the present distribution of payments.

The act provides that after a channel 30 feet deep and 350 feet wide is secured, $100,000 per annum shall be paid for its maintenance during twenty years. This clause should be amended to apply to the 30 feet channel above described. The $1,000,000 reserved by the jetty act to be held in the United States Treasury as security for the performance of this part of our obligations will remain undisturbed.

We undertook the construction and maintenance of these works for $692,110 less than the official estimate of the Commission upon whose report the act was framed. We also assumed the whole risk of their failure to produce the desired channel, notwithstanding the confident and reiterated predictions made by official and other experts that they would be unsuccessful. We likewise took all the risk of their destruction by storms and treacherous foundations—dangers which were believed by many to be insurmountable. Besides all this, we were not permitted to improve the pass of our choice, with its normal depth of 15 feet, but were given one only a quarter as large, with a depth of but 8 feet. In spite of the natural difficulties which were to be surmounted during a period of unusual financial prostration, we have carried this enterprise to a point where its complete success is acknowledged even by its opponents. We have changed the little pass into a grand channel of commerce, through which the largest shipping that visits the port of New Orleans floats in safety; while every prediction of failure and of re-formation of the bar in advance of the jetties, is shown by official surveys to have been without foundation.

We ask no increase in the price of the work, nor do we ask to be

relieved of the obligation to create a permanent channel 30 feet deep through the jetties, and that shall be fully as wide as the size of the pass will justify. We ask no legislation to retrieve forfeited privileges or lapsed concessions, nor the assumption of any risk of outlay for doubtful benefits. We ask simply that a reasonable portion of moneys actually expended may be repaid to relieve embarrassments resulting from provisions in the law unusually severe and oppressive, and which cannot now be retained without injuriously reacting upon the commercial and industrial interests of the country. We have striven to carry through by private means and individual hazard, the largest and most important public work ever undertaken by the government, and have forborne, under many discouragements, to ask relief from the stringent conditions of the law until the official reports of the most eminent engineers of the government have confirmed the public faith in our complete success; and now that sheer necessity compels us to do so, we only come after the changing tides of commerce attest the substantial benefits already reached, and after the people are assured that private enterprise and courage have promptly secured, at moderate cost, "an open river mouth" for the Mississippi in lieu of the more costly and dilatory method proposed of a canal with locks. And with this record we ask no payments on the work that will not leave in the hands of the government an ample amount of our compensation to insure the entire completion of the jetties.

With great respect, I have the honor to be,

Your obedient servant,

JAS. B. EADS.

Hon. GEORGE W. MCCRARY,
Secretary of War, Washington, D. C.

REVIEW

OF LETTER OF GEN. A. A. HUMPHREYS, CHIEF OF ENGINEERS U. S. ARMY, MAY 1, 1878, TO HON. E. W. ROBERTSON.

WASHINGTON, D. C., June 1, 1878.

To the Hon. E. W. Robertson, Chairman Committee on Levees and Improvement of the Mississippi River, House of Representatives:

Dear Sir,—I have just read with astonishment a letter addressed to you, dated Washington, D. C., May 1, 1878, and signed by A. A. Hum-

phreys. As the writer holds the office of Chief of Engineers, U. S. A., he is in a position to have at hand reliable official facts which emphatically refute many of the statements contained in his letter respecting the jetties at the South Pass. The letter seems ostensibly intended as a protest against the improvement of the Mississippi river being in anywise entrusted to me. He assumes that the bill providing for a commission of five engineers to prepare plans for the improvement of the river is designed to place its whole control in my hands, whereas the only bill reported from your committee to the House six weeks ago provides that three of the five engineers shall be taken from the army, and that one of these three shall be president of the commission. So far from my expecting to have the presidency of it, the bill prevents the possibility of such a thing. Nor have I ever expressed to a single member of the Senate or House a wish to have its provisions altered, nor have I authorized or requested any one to secure the presidency of the commission for me.

I shall reserve the discussion of the views entertained by General Humphreys and myself, respecting the improvement of the river, until a more convenient season. It is sufficient to say here that they are totally different. I cannot, however, permit some of the statements in his letter respecting the jetties to go unchallenged.

General Humphreys says the views of the Engineer Department are to be found in its reports as far back as 1852; "notably in the Physics and Hydraulics of the Mississippi river, pages 442 to 456, * * * where it is demonstrated that, by the use of jetties, the channels at the mouths of the river may be deepened to the full depth of the Pass to which they are applied."

It is encouraging to see that General Humphreys desires to be recognized as one of the earliest to suggest jetties for the improvement of the mouth of the Mississippi; and, as the South Pass has a depth through it of 30 ft., this testimony will probably remove from the minds of those who consider him an authority upon the jetty question all doubt as to the ability of the jetties to produce the maximum depth I have undertaken to secure.

General Humphreys, in his letter, refers to the earlier reports on the jetties by General Comstock to prove that the bar had advanced four or five hundred feet in May, 1876. The answer to this absurdity will be found in a comparative chart of surveys of the outer crest of the bar, made by the United States Coast Survey in May, 1875, before the jetties were begun, and in May, 1876, accompanied with a statement from the Superintendent of the Coast Survey, Hon. C. P. Patterson. They were furnished in compliance with a resolution of the House of Representatives, and duplicates were at the same time, August 1, 1876, sent to the War Department. Reference to them will show that, instead of there being an advance of the bar, there had been excavated by the current, from a space 2,100 ft. square in front

of the jetties, 68,400 cubic yards of material in excess of deposits made in that area during the year.

General Humphreys says:

"By the next report of Captain Brown, August 1, 1877, showing the condition of the work July 24, 1877, we find the total extension of the bar up to that date to have been 600 ft., the depth on the greater part of the bar varying from 15 to 20 ft. flood tide; on the inner eastern side the depth being about 21 ft." A foot note says, "see the maps accompanying these and previous reports."

The report of Captain Brown, August 1, 1877, shows no such extension, nor do any of his maps. On the contrary, he says, on page 26:

"On sheet No. 4 will be found the results of a survey on June 20 to June 22, 1877, of a mile or more beyond the ends of the jetties and for a considerable space on either side. A comparison of this chart with that of the survey of June 20 to June 24, 1876, reveals the following regarding various curves of equal depth: Averaging, the 20-ft curve has receded about 200 ft.; the 30-ft. curve about 300 ft.; the 40-ft. curve has remained nearly stationary on the whole."

The curves referred to indicate the form or contour of the outer slope of the bar between the depths of 20 and 40 feet.

By reference to Captain Brown's chart No. 4 it will be seen that an area of about one square mile in front of the jetties is embraced in this survey, and this has been subdivided by him on the chart into 21 sections, the whole forming a fan-shaped area in front of the jetties. A portion of this area—sections No. 1, 7, 13 and 21—lay to the right and left of the end of the jetties, and out of the track of the river's discharge. Referring to this chart, Captain Brown, on page 28, says:

"Taking into account all the divisions, except 1, 7, 13 and 21, we find that the scour in the year was 1,145,976 cubic yards, equivalent to a scour of 1.3109 feet, or one foot and three and seven-tenths inches, over this latter area."

By a glance at the table on page 30 of the report it will be seen that section 17, containing about 38 acres, had an average depth of 29.28 ft. in 1876, and in 1877 this depth had increased almost four feet, viz., to 33.25 ft.

It is thus shown that General Humphreys' statement is not only directly refuted by Captain Brown's report, to which he refers, but that the bar, during the twelve months, had actually receded 200 or 300 ft.; that the bottom, for a mile in advance of the jetties, had deepened one foot and three tenths, and that the portion immediately in front of the jetties, 38 acres in extent, and precisely where General Humphreys predicted the re-formation of the bar would occur, had actually deepened in one year nearly four feet.

General Humphreys says:

"The next report of Captain Brown, December 23, 1877, was made

after a powerful newly-constructed dredge had been working on the bar seaward of the jetties for a month, by which means the depth on the bar had been increased, and a channel 22 ft. deep at flood tide and 200 ft. wide had been secured."

On page 17 of this report Captain Brown says:

"When the new dredge began its experimental work, the interruption to the 22-ft. channel, *i. e.*, from 22 ft. inside on the bar to 22 ft. outside, was 50 ft. only."

On page 19 he says:

"In obtaining the channel 22 ft. deep for a width of 200 ft., the dredge Bayley has worked about twenty days, of ten hours each."

Soon after the channel referred to was obtained, entitling me to the second payment of $500,000, the Secretary of War directed a commission of engineers, composed of Generals Barnard and Wright, U. S. Engineers, to visit the works, and among other subjects they were required to report upon the following interrogatory, viz.:

"Have such depth and width of channel been obtained by the action of such jetties and auxiliary works as are contemplated by the terms of the act of Congress aforesaid?"

The report of this Commission will be found in Ex. Doc. 37, 45th Cong., 2d Sess., House of Reps.

In answering this interrogatory, the Commission says, on page 5:

"If we look at the actual facts presented by the prosecution of this work, we find that where two and a half years ago there was a bar at the Mouth of the South Pass of over two miles of extent, measured from 22 ft. water inside to the same depth outside, over about one-half a mile, of which there was but 8 ft. of water, 'a wide and deep channel' of 22 ft. depth now exists, and a result inferior in physical magnitude but no less in importance at the head of the passes has been obtained. And these results are so exclusively due to the jetties and auxiliary works, that the auxiliary aid of 'appliances,' if in such we include dredging machines, is utterly insignificant, consisting mainly, indeed, in a slight widening at two points, and widening and deepening a third."

General Humphreys says, in italics:

"*Yet the facts exhibited by the reports of the officers inspecting the South Pass show that the views expressed by many engineer officers, the Chief of Engineers among them, that a new bar would form at the sea end of the jetties, and that it would extend into the sea more rapidly than the old bar, are correct, even during the changes going on under the scouring power of the jetties, aided by dredging between and seaward of them.*"

General Humphreys predicted (see page 677, last edition Physics and Hydraulics) that the bar, under the action of jetties, would advance 670 feet annually. Instead of this bar advance, as predicted, there is shown to have been no advance at all, but an actual recession. He, however, proceeds to say:

*"And it is also evident that the only method of permanently maintaining a deep channel to the sea is to constantly extend the jetties into the sea in advance of the bar. * * * It was precisely this objection to the jetty system which the Chief of Engineers and other engineer officers made."*

Captain Brown, on page 26 of his seventh report, August 1, 1877, says:

"It must be noted in regard to the recession of the 20 ft. and 30 ft. curves, that the present end of the east jetty is 330 ft. north of what I have always called the old end of the east jetty, and the present end of the west jetty is 263 ft. northerly of the point formerly considered to be the end of the west jetty."

The meaning of this is that, instead of having to advance the jetties 670 feet every year, as predicted, at a cost of $670,000 (see page 677, last edition Physics and Hydraulics), they are actually more than 200 feet shorter to-day than they were originally intended to be. The deepening has been so marked at the sea ends of the jetties, where the predicted bar growth was to occur, that I have not found it necessary to complete them as far out as they were located and partly built two years ago.

This notable difference between his declarations and the official reports I have quoted, proves that on the subject of the jetties General Humphreys is not a trustworthy authority.

General Humphreys says:

"*To make a channel through it* [the 'bar growth,' as he calls it], *and to endeavor to maintain the channel, dredging has been resorted to precisely as was done on the Southwest Pass bar, a process which it was designed by Congress to dispense with in entering into a contract for deepening the South Pass channel by the construction of jetties and auxiliary works.*"

The Commission, from whose report I have before quoted with reference to dredging, states on page 4:

"If, however, we refer to authoritative statements of the methods of applying that principle, we find it stated in the Physics and Hydraulics [page 489, reprint], in treating of the 'plan of jetties,' that 'the erosive action should be aided at first by dragging and scraping the hard portion of the bar.'"

Having himself pointed out in the Physics and Hydraulics the importance of "dragging and scraping" as an auxiliary of the jetty system, his objection to my use of a dredge at the South Pass is without force. But that it was clearly my right to hasten the development of the channel by dredging is shown by the Commission to whom this question was referred. It says, page 4, after referring to an item of $250,000 estimated for dredging by the previous Commission of 1874, in connection with the jetties:

"We conceive, therefore, that the true intent of the proviso does not prohibit the auxiliary aid of dredging; that its spirit is as above defined, and that, indeed, in the authorizing of the employment of

such boats, rafts, and appliances as he may in the 'prosecution of said works deem necessary,' allows dredging, and should not prohibit payment for channel widths and depths which the jetties and auxiliary works have to all intents and purposes really created, and to which dredging has been slightly auxiliary."

Of the cost of the jetties, General Humphreys says in his letter:

"This subject is further treated in still more detail in Ex. Doc. 220, House of Representatives, 43d Congress, 1st Session, and an estimate of the first cost of applying jetties to deepen the Southwest Pass to 28 feet is given, as well as the first cost of the same for the South Pass; the cost of permanent works for the former being $7,000,000, and for the latter less than $5,000,000. For less permanent works the cost in each case, it is stated, would be one-half the sums named."

General Humphreys evidently intends to create the impression that he showed to Congress in 1874 that the jetties could be built for less than the price to be paid to me.

In Appendix M, page 677, Physics and Hydraulics, last edition, the cost of applying the jetty system to the Southwest Pass is stated at $23,000,000, and the cost of applying it to South Pass, after adding $670,000 per annum for extension and $100,000 per annum for dredging, is thus expressed:

"The total cost to the Government of securing permanently a depth of twenty-seven feet at low water by this Pass will then be about $17,000,000."

Thus to defeat the jetty bill in 1874 and secure the construction of the Fort St. Philip canal, the cost of which is stated on the same page to be but $13,000,000, the official assurance was given that the jetties at South Pass would cost $17,000,000; and now the same eminent authority who made that statement, wishing to depreciate the value of my works, leads you to believe that he only estimated the cost of jetties in 1874 at less than $5,000,000.

I have shown conclusively, from official reports on the jetties, that there has been no advance of the bar; that it has not been necessary to extend the jetties, and that there has been no shoaling in front of them. These three facts are precisely the opposite of the results predicted by General Humphreys. It is evident, from these extracts, that the conviction which General Humphreys entertained in 1874, that the jetty system, if applied to the Mississippi River, would prove a failure, has become so fixed in his mind that he is unable to realize the emphatic official declarations of the officers of his own corps, which testify to their complete success.

The act of Congress of March 3, 1875, provided:

"Said Eads shall be untrammeled in the exercise of his judgment and skill in the location, design, and construction of said jetties and auxiliary works."

This meant that, having undertaken an important work at the risk of myself and associates, I should have no hostile interference on the part of the Government so long as I should faithfully carry on the work. In contempt of this provision of the law, the Chief of Engineers, in the summer of 1875, when I had just begun the jetties, set himself assiduously to work to impeach my judgment and skill, and to show that the enterprise would be a failure. Not only was his time given to this effort to defeat the purpose of Congress, but the public money was used to print his "memorandums" against the South Pass jetties. These were issued in pamphlet form for circulation, to lessen the public confidence in my undertaking. They were then put in his annual report for 1875; and in 1876 they were reproduced with added matter in the last edition of the "Physics and Hydraulics of the Mississippi."

This was not only an injury to me, but was a flagrant disrespect to Congress, whose act had provided that I should be free from such interference.

The fact that Congress, in passing the jetty act, had disregarded the unsound views of General Humphreys, would fairly excuse his loss of temper, but could not justify this reproduction, at the public cost, of his repudiated theories.

Although the jetty act was purposely framed to exclude General Humphreys from all connection with the work (because of his hostility to it), by providing that the inspecting officer should be dedetailed to report to the Secretary of War, General Humyhreys gave the officer his instructions, and the reports were made to him during the first year, when his interference and hostility became so pronounced that I appealed successfully to the Secretary of War, in an open letter, May 23, 1876, to have him absolutely excluded from any further connection with the work, and to have the inspecting officer report directly to the Secretary of War, as the law provided. And now, on the very day when a measure to secure the more vigorous prosecution of the work is reported to the Senate from the appropriate committee, General Humphreys presents the letter I am reviewing, evidently with the intent to defeat this measure; and as a pretext for presenting it, asserts that a bill has been introduced in Congress to give me the control of the further improvement of the Mississippi River, when he must have known, or could easily have ascertained, that no such bill has been reported by your committee, or any other.

And, in absolute defiance of the plainest official evidence to the contrary, Gen. Humphreys makes the astonishing statement that "*the results actually attained at the South Pass disprove the views of Mr. Eads and confirm those of the Engineer Department;*" while the safety and ease with which the heaviest draught ships already use the jetty channel, and the immense benefits resulting to commerce,

should convince even him of the wisdom of the Government in rejecting the advice of the Chief of Engineers when deciding on the problem of improving the mouth of the Mississippi River.

Very respectfully,

JAS. B. EADS.

LETTER

TO THE STOCKHOLDERS OF THE SOUTH PASS JETTY COMPANY.

ST. LOUIS, June 28, 1878.

At a meeting of stockholders of the South Pass Jetty Company in New Orleans, held just before the receipt of the second payment of a half-million dollars from the United States, for obtaining 22 ft. of water, I explained to the meeting the fact that, owing to the large proportion of the whole work that was found necessary to be completed to secure a 22-ft. channel of the requisite width through the jetties to earn that payment, I was compelled to incur debts in the construction of the work to an extraordinary amount, and unless I could discharge the most urgent of these liabilities, and be provided some means to continue the further prosecution of the work, I would be absolutely compelled to suspend all further operations.

Of the payment then about to be made by the Government, $370,000 had been assigned by me to the South Pass Jetty Company. The stockholders present at the meeting in New Orleans, recognizing the propriety of discharging the debts which had been incurred to earn this payment, as far as they were immediately pressing and burdensome, and also of providing means by which the future payments from the United States could be secured, addressed the following letter to the Board of Directors of the Company:

"NEW ORLEANS, December 18, 1877.

"*To the President and Directors of the Jetty Company:*

"Gentlemen,—Mr. Eads has explained to the undersigned stockholders of the South Pass Jetty Company that, to secure the present depth of 22 by 200 ft. channel through the jetties, he has been compelled to execute a much larger portion of the works originally contemplated, and to build a dredge boat to correct parts of the channel where the deepening by the river forces has been less rapid than was expected; and to do this he and the contractors, James Andrews &

Co., have had to incur large individual liabilities, the payment of which has been promised so soon as the second installment from the United States Government, now due, shall have been received; and to discharge these obligations, and to distribute out of this payment to the stockholders of this Company the full amount agreed upon in its contract with Mr. Eads will leave him without the means to operate the dredge boat and construct additional works of importance, which are essential to insure both the permanence of the present works and to obtain the third and other installments from the United States.

"For these reasons we hereby agree to waive our right to the full amounts severally due us according to the terms of the contract made with him, and to accept from the installment now due a dividend of twenty (20) per cent. on our stock, on condition that the remainder of the dividend we would otherwise be entitled to be satisfactorily secured to the Company, to be paid with 10 per cent. interest out of the deferred payments to be due from the United States for securing and maintaining 24 ft. of water.

"You are therefore hereby requested to limit the second dividend to 20 per cent., and to loan the remainder, which would otherwise be due to us, to Mr. Eads, to enable him to discharge the debts contracted on account of the jetty works, and to continue the prosecution of the same."

(Signed by the stockholders in New Orleans.)

And a copy of this letter having been sent to the stockholders generally, responses were received showing that holders of more than four-fifths of the stock concurred in the request that a dividend of 20 per cent. be made.

The proportion of the second payment belonging to the Company was paid by me to the Directors on the 17th day of January, 1878, and on the 19th the Board ordered a circular to be sent to the stockholders, from which I extract the following:

"JANUARY 19th, 1878.

"The following action was this day taken by the Board of Directors of the South Pass Jetty Company, * * * * all being present, and the vote being unanimous:

* * * * * *

"And whereas, we have ascertained, from representations of Captain Eads, that it is absolutely and imperatively necessary for him to have a larger sum of money than would be due him, out of the payment just made by the United States government, in order to continue the work and secure the next payment; and,

"Whereas, out of the 100 stockholders of the company, 78, representing $320,300 of the stock of the company (being more than three-fourths of the whole amount of stock issued), have *requested* the board of directors to reloan Captain Eads all over twenty per cent. of the amount due the company from the second payment, and have agreed to receive twenty per cent. of the amount at this time:

* * * * * *

"We therefore call the attention of the stockholders who have not yet signified their assent, to these facts, and ask that all who are willing to take the said twenty per cent. and authorize the board of directors to loan to Jas. B. Eads the balance which would be due them each from said second payment, will forward to the president

of the company their assent, to the end that the imperative needs of Captain Eads to continue the favorable working of the jetties, may be furnished at once, and the stockholders secure the full benefit of their investment."

This was responded to by holders of more than four-fifths of the stock. Stockholders, representing less than one-fifth of the stock, declined to consent to the wishes expressed by the remainder of the company; and the directors held unanimously that the board had no right to withhold from any stockholder, without his consent, any part of his *pro rata* of the amount paid by me to the company. Therefore, every stockholder of this minority refusing to receive 20 per cent. was paid 78 per cent., except two or three who demanded but 50 per cent.

By the refusal of the board to take the responsibility of carrying out the wishes and views of four-fifths of the stockholders, as clearly set forth in their letter above referred to, I was deprived of the use of about $50,000, which would have enabled me to reduce and renew some of the pressing debts referred to, and would have left sufficient funds to execute important work by which an earlier development of the channel would have been produced, and future payments from the United States secured at an earlier date. In consequence of being deprived of the above sum, the work has been greatly delayed, and the utmost exertions on my part, coupled with extraordinary offers of compensation for advances of money, have scarcely sufficed to provide means to pay the current expenses of a greatly reduced number of employees; while nothing but the confidence and liberality of a few of the stockholders, who received only the 20 per cent. dividend above named, has enabled me to maintain this small force, and keep the dredge boat at work, by supplying me with all the coal and stores needed at the works, on the assurance that these would be paid for out of the next payment received from the government.

The refusal of the board to carry out the wish of the majority of the stockholders, by which one party has received the whole of their original investment and 28 per cent. profit in addition, while the other party has received but 70 per cent., has naturally excited much dissatisfaction. In consequence of this feeling, I have received the following letter:

"NEW ORLEANS, LA., May 18, 1878.

"*Capt. James B. Eads, St. Louis, Mo.:*

"DEAR SIR,—The undersigned stockholders in the South Pass Jetty Company desire to call your attention to the injustice done them in the distribution of the moneys collected by you from the United States, and paid by you to the company.

"Knowing the necessity of sustaining you in carrying on the work, a large number of us, representing about 80 per cent. of the stock of the company, addressed a letter to the president and directors of the the company, requesting that no dividend exceeding 20 per cent.

should be paid to the stockholders from the last payment received by you from the government, and recommending and consenting to the re-loaning to you of such other portion of said money, exceeding 20 per cent., as we were entitled to.

"Although a circular, signed by the president and directors of the company and addressed to the stockholders, was issued by them approving our request, we have learned with much surprise that dividends of 78 per cent., amounting to about $50,000, were nevertheless paid out to a portion of the stockholders.

"As this was manifestly unjust, if not unwise and illegal, we wish to call your attention to the matter in the hope that you will take such steps as may be necessary to equalize the dividends on the stock, if it be in your power, especially as we believe that your inability to prosecute the work has been caused by this action, and has resulted in delaying the receipt of the twenty-four feet payment.

"Respectfully yours."

(Signed by stockholders representing a large proportion of the capital stock,)

Fully appreciating the injustice to these stockholders, and the impolitic action of the board, and having received a formal demand from the president of the company, authorized by a recent resolution of the board, to pay over the amount just received by me in accordance with the recent action of Congress, and feeling assured that the board will not be controlled by any other policy than that pursued by it in the last distribution, I have determined after much reflection, and consultation with several of the largest stockholders, to pursue the only course by which the wish expressed in the letter last named (May 18) can be accomplished, namely, by remitting to each stockholder who has received but 70 per cent., as large a portion of the payment just received as is possible after paying such portion of the obligations as are immediately pressing, and which have been incurred by the prosecution of the works, and paying no portion of such payment to those stockholders who have received already an equal or greater *pro rata* on their stock.

The long delay that has occurred in receiving our payments has largely increased the matured indebtedness against the works, whilst the crippling results of the recent unequal distribution has disabled me from extending many of the debts immediately due. In addition to this, the further relief provided by Congress, in the act hereunto appended, is provided only to meet actual work *hereafter* to be done, and this is to be deducted out of the next half million to be earned by an increased improvement in the channel. I can not, therefore, look to the realization of any aid from those payments with which to pay any part of these debts, and therefore I have deemed it not only strictiy just that such debts should first be paid out of the amount just received, but that such payment is in strict accordance with the views of the large majority of the stockholders signing the above letters. It is evident that they differ from the views of a majority of

the directors, and that they do not approve of a distribution of *profits*, while debts incurred to obtain the money from the government remain unpaid, to employees, and to parties who have supplied materials, machinery, etc., at market prices, and to banks which have loaned us money at ordinary rates of interest. Under these circumstances I have concluded that it was my duty to adopt and carry out the views of so large a majority of the stockholders rather than those of some of the directors. The debts referred to are as follows:

Notes due to banks and others for loans which have been expended on the works and for machinery, etc		$239,240 21
Amounts due employees		14,314 18
Amounts due for coal, stone, stores, materials, repairs, etc., as per balance sheet, June 15,	$87,364 58	
Wages, etc., for June, estimated	10,000 00	97,364 58
		$350,918 97
Amount required to pay all stock up to par		141,950 00
		$492,868 97

The payment of these debts leaves but 30 per cent. as applicable on such stock as has already received but 70 per cent., and I trust when it is remembered that this will return to each stockholder the full amount of his investment, and that James Andrews & Co., Contractors, have not yet been paid a sufficient sum to restore to them half the actual capital invested by them in the works, and that the portion of the debts above-named, on their account, are only such as are absolutely imperative, the present payment on the stock will be deemed not only full justice to its claims, but as large a payment as justice to urgent creditors will warrant. As to the ultimate payment of the full profit and interest promised to all of the stockholders, I am justified in giving the most emphatic assurance that every dollar of it will be paid in full within a reasonable period, and therefore trust they will exercise such patience and forbearance as have been made necessary by unlooked-for opposition, misrepresentation and difficulties which I and my immediate coadjutors have endeavored to meet and overcome to the best of our abilities. In this immediate connection I cannot too highly praise the earnestness, confidence and ability by which I have been sustained under many discouragements by Col. James Andrews, Mr. R. S. Elliott, and all of my assistants in the engineering, constructing, and clerical departments of the work. All of these gentlemen have aided, by their intelligent and zealous co-operation, in lightening my labors, and have all evinced their faith in the enterprise in various ways.

I would respectfully suggest the propriety of having a stocholders' meeting to determine matters of future interest. The unforeseen necessity of changing the assignments hitherto made by me to the Company, and substituting more remote payments to secure the stock-

holders, and the provisions of the recent act of Congress by which advances by the Government depend upon the assignment to it of payments which have in part been assigned to the Company, make it necessary that a readjustment of these assignments be made, by which the rights of stockholders may be fully secured, with due regard to those of other parties interested in future payments.

Respectfully,

JAS. B. EADS.

REVIEW

OF THE REPORT OF THE BOARD OF U. S. ENGINEERS APPOINTED UNDER THE ACT OF CONGRESS, APPROVED JUNE 19, A. D. 1878.

This report, although in some respects objectionable (as will hereafter be shown), effectually settles several important questions which have been much controverted. These will be first considered.

RESULTS IN FRONT OF THE JETTIES.

Prominent among the evils which were prophesied by the enemies of the jetties, was that of the formation of a bar at their mouth. It was declared that if a deep channel *could* be obtained it would have no permanent existence, but would soon be rendered valueless by an advance of the bar. So persistent has been this cry of BAR ADVANCE, in official and unofficial publications, and so widely has it been circulated through the medium of the press of the country, that these predictions have given rise to grave doubts upon the subject in the minds of many of those who were deeply interested in, and who sympathized with this effort to give relief to the commerce of the Mississippi river. Facts were not wanting to dispel these doubts. The reports from time to time of the government officer in charge of the work (Captain Brown), the charts which he submitted from official surveys made by himself, conclusively demonstrated the utter falsity of all allegations in regard to a "bar advance;" but in the face of these reports and accompanying charts, the enemies of the work have persisted in repeating their assertions to the contrary. The report of the Board of Engineers, which we are now considering, certainly puts forever at

rest this much vexed question, and dispels all doubt upon the subject. In considering this question of "bar advance," the board unanimously says:

"In connection with the 'probable results' of jetty construction, upon which we are directed to report, there is one to which pre-eminent importance has been attributed, and which should not be here overlooked—that of bar advance. * * * * If, in this connection, we take into account the position of the 30 feet curve outside the jetties (and this is evidently a better test), there is shown, instead of advance, *an absolute retrogression.* Or, again, if we have reference to deeper curves, Captain Brown's surveys (Annual Report, table, p. 15), show that from June, 1877, to July, 1878, the 40, 50, 60, 80, 90 and 100 feet curves had drawn in towards the ends of the jetties the respective distances of 117, 228, 190, 65, 71 and 183 feet, the 70 feet curve alone showing advance into the Gulf (46) feet. *The actual results, therefore, so far as we know them, do not justify the predictions of accelerated bar advance. On the contrary, they show a disappearance of bar material from the front of the jetties.*"

RESULTS WITHIN THE JETTIES.

The next important matter settled by the Board is that relating to results produced within the jettied channel. The opponents of the jetties, as we have seen, started with the prediction that no reliable results would be achieved, and sought to induce the belief that the improvement from time to time in the channel was not a general one, but that a deepening in one place involved a shoaling in another. The report of the present Board disposes very summarily of all such assertions. After quite an elaborate detail of the results produced, the Board says:

"The maximum bar depth that has been obtained prevailed December 14, 1877, when it was 23.7 feet. At the date of the latest survey, December 28, 1878, it was 23 feet. This slightly decreased bar depth by no means indicates actual retrogression in the progress of results. On the contrary, *there has been constant progressive general improvement in the jettied channel, at no time more evident than at present.*

"At the date last named a depth of 24 feet, with a channel width of 300 feet, extended down to within 2,000 feet of the jetty ends, and the same depth with a channel width of 200 feet almost to the very ends. Thence to the same depth outside was a distance of but 60 feet, with a navigable channel of 23 feet intervening.

"The 25-ft. channel has nearly the extent of and not much less width than the 24-ft. channel. From its terminus inside to the same depth outside of the bar, there is but an interval of 160 feet."

PERMANENCY OF THE WORKS.

Another question of interest and importance settled by the Board is that relating to the "permanency of the works." This is of course a matter of great moment, as it involves the question whether the

good results produced can be permanently maintained. In reference to this matter the Board says:

"*Wave* (or storm) *action* of the sea and *decay* or *destruction by the teredo* of the willow mattresses are the principal destructive elements to be mentioned; an additional element of deterioration not peculiar to the location, but supposed to be so prominent as to involve the question of permanence, must also be noticed. The jetties, except the extreme ends and contiguous portions, for about 1,500 ft. inward, are so well sheltered by shoals that wave action, except on those portions, has little effect. On the sea ends the effect has been considerable, but mainly superficial, destroying more than once the upper course or courses of mattresses, and washing off and scattering the stones (mostly small) which have been repeatedly applied to the top surface. Wave action is by no means as violent here as in similar exposures on the Atlantic coast. We see no reason to doubt that the thick concrete capping Mr. Eads is now commencing to apply (work having already begun on the upper portions), flanked by enrockments of heavy stones on palmetto log grillages, overlying the original marginal mattresses, will resist sea action.

"Wood of all kinds, considerably submerged, is sufficiently secure against decay.

"Experience here shows that for about 1,700 feet inwards from the jetty ends the teredo destroys rapidly all exposed wood (including in this term the willows of the mattresses) lying more than four or five feet below the surface of the water. Evidence enough of its attacks upon piles and willows exists. But the teredo does not attack wood where the free access of sea water is impeded. Those portions of a stick buried in mud or sand, or packed around with mud or sand, are secure. We have no reason to believe that the teredo has penetrated or can penetrate far into the interior of the mattress courses; we have pretty good reason to believe that the foundation mattresses are and will remain secure; and probably also the bulk of the interior of the masses of willow work.

"In what we have said under the head of 'progress' we have given sufficiently full details concerning settlement. It is still very great at the outer ends, though very much less in all those portions more than two or three thousand feet from these ends. That additional superficial applications of stone or concrete will be necessary to the structures we must expect.

"In the ordinary sense of the word, permanency, *i. e.*, capability of endurance of destructive forces, the works may be said to possess the attribute to a reasonable degree for work of the kind, thus situated. As regards the outer ends, it is yet early to predict to what extent or how long renewals of height, to compensate the still progressing settlement, must be resorted to."

MODIFICATION OF THE SPECIFIED DIMENSIONS OF CHANNEL.

Having thus emphatically certified to the complete success of the jetties, the Board proceeds to consider the advisability of modifying the jetty act as regards dimensions of channel and terms of payment. These matters we will notice in their order; and 1st, as to "dimensions of channel."

An official letter, which I addressed to the Board under date of

January 4, A. D. 1879, contained the following urgent request, which is here put in italics:

"With respect to a modification of the dimensions of the channel described in the act, I earnestly hope the Board will state the probable size which the normal discharge of the pass is capable of maintaining between the jetties when they are fully consolidated and completed, *and that it will also express its views as to the advisability of undertaking to maintain one of greater dimensions, by forcing an increased volume through it.* The results which have been developed thus far by the works seem to me to correspond in a remarkable degree with the effects which were anticipated by the Commission of 1874, and to indicate that the maximum capacity of the pass was correctly assumed by the Commission. To produce the maximum channel described in the act will, I think, involve the necessity of a central depth throughout the jetties of not less than from thirty-five to forty feet.

"The natural volume of the pass can not, I am confident, create so great a depth through the jetties, and if it be insisted upon by the United States, it can only be produced by forcing more water through the pass. This will involve, in my opinion, danger to the jetties, and a disturbance of the regimen of the three passes to an extent that can only be known after it is probably too late to remedy the evil."

Having submitted this request for an expression of opinion upon a matter so manifestly important, and so clearly embraced within the duties imposed upon the Board by the act of 1878, I confidently expected a response.

It will be at once apparent to even the casual reader that the question submitted was a vital one. If the safety of the works be endangered, and the destruction of the good results achieved be possible, from forcing an unnatural quantity of water through the pass, thus again placing fetters upon the now free commerce of the river; and if the works now erected are likely to produce a channel sufficient for the present and prospective wants of commerce, it would seem plain that the question is one which should have commended itself to the most careful attention and consideration of the Commission. That a 26 feet channel is entirely adequate would appear from the fact that the Commission of 1874, instituted by act of Congress to determine the best method of securing an outlet from the Mississippi River to the Gulf, recommended in its report a resort to the jetty system, claiming that by that system a channel 25 or 26 feet could be secured.

In this connection it may also be noticed that the president of the present Board (General Barnard), in a minority report on the Fort St. Philip canal project, dated January 29, 1874,* gave expression to the following opinion:

"With 20 feet at extreme low tide, vessels drawing 22½ feet could,

* See Report of the Secretary of War, 1874-'75, vol. 2, part 1, p. 844.

owing to the softness of the bar, frequent the port of New Orleans, and for mere commercial purposes probably 20 feet draught would be adequate. A draught of 23 feet will include 85 per cent. of the shipping of the world; and with a draught of but 18 feet, vessels (steamers) can be built of 5,000 tons, carrying 70,000 bushels of corn, or about 11,000 bales of cotton. It is clear, then, that for commercial purposes a depth of 20 feet on the bars of the passes will suffice to furnish a navigable outlet, and relieve the commerce of the valley from enhanced charges arising from insufficient tonnage in the transports."

A perusal of the report of the present Board will show that it utterly ignores the important question submitted to it by me, and that its recommendations are entirely uninfluenced thereby. It says:

"In view of our recommendation that Mr. Eads be provided with sufficient funds to complete his work according to his own programme, as explained to us, and of his expressed ability to obtain virtually the depths and widths of channel prescribed; and further, as but a short time need elapse before results of completing his plans will be made manifest, this Board thinks it premature to recommend at this time any changes in channel dimensions as required by the contract."

The "expressed ability to obtain the depths and widths of channel prescribed," attributed to me by the Board, may have some light thrown upon it by a reference to a portion of my official letter before quoted. I say in it:

"The natural volume of the pass cannot, I am confident, create so great a depth through the jetties, and if it be insisted upon by the United States, it can only be produced by forcing more water through the pass. This will involve, in my opinion, danger to the jetties, and a disturbance of the regimen of the three passes to an extent that can only be known after it is probably too late to remedy the evil."

It is passing strange that I should have been so misunderstood by the Board.

A Board composed, as this one was, of several of the most distinguished members of the Corps, could not have failed to appreciate the vital importance of a question which not only involves the stability of the jetties, but the regimen, or sensitive adjustment, which nature has established between the different inclinations of the surfaces of the main river and its three chief outlets, and their respective volumes of water, by which adjustment the velocity of current in each channel is so tempered that the floods of the parent stream are discharged through it year after year without rapid or important alterations in its size, although each flows through a bed formed by the most recent and sensitive deposits of the delta—deposits which are swept away or added to with every abnormal increase or diminution of velocity. The slope or fall per mile of each pass and of the main river is different in each channel, and if the volume flowing in either be increased or diminished, the current velocity must be al-

tered, and it is then no longer adjusted to carry the sediment with which it is charged through such channel without deposit or scour occurring. The result of such disturbance of regimen, therefore, tends at once to produce results which, if unchecked, may lead to the extinction or filling up of the pass with deposits on the one hand, or its continual enlargement on the other until it may at last discharge the entire volume of the river, and thus destroy the other passes.

That two members of the Board, at least, had settled convictions upon this important question, and that the entire Commission of 1874 fully agreed with them, is evident from the testimony given by these two members (Generals Barnard and Wright) before a committee of the Senate in 1878. General Barnard, in his testimony, said:

"Question. Suppose the scouring force between the jetties should deepen it from 7 to from 23 to 24 feet; now suppose the scouring force with the present water in it is exhausted at 24 feet, would it be safe to turn in any water from the Southwest Pass and from Pass a'lOutre from the main river, through this South Pass, to add to the scouring, to make it 30? Answer. I have no confidence in it; nor was that ever recommended by the Board of 1874. I do not say it cannot be done, but to be safe I would say it should be a slow process. It would require much labor and great expense. It would create an additional 'head,' and the results in the case of that kind are not easily foreseen. If done at all, I would advise it to be done very carefully and slowly, and in that way probably more water could be directed into the pass. It would have to increase its own section all the way down in order to carry that water."

General Wright, in answer to the question as to the advisability of forcing more water into the South Pass, in his testimony, said:

"The Commission of 1874, which got up the original plan of the jetties, discussed that matter at great length, and it was, I think I may say, the unanimous opinion of the members that the size of the pass could not be interfered with; that what we wanted was that the regimen of the pass should not be disturbed; and to that end there is put into the estimates a certain amount (I don't remember whether specifically or not, though I think it was) to prevent any enlargement of the pass at all."

In the face of this record further comment is unnecessary.

MODIFICATION OF TERMS OF PAYMENT.

We next come to consider the recommendations of the Board as to the advisability of a modification of the act of A. D. 1875, as regards "terms of payment." In its consideration of this question the Commission does not exhibit that breadth of view which would be expected from officers of such high rank and character. The Board approaches the matter from a most unfortunate standpoint. It adverts to the fact that Congress did not leave "the execution of the work to its own agents." It will be unnecessary now to discuss the

question as to whether Government engineers should have a monopoly of Government work, and the civil engineers of the country be excluded from all participation therein, and this regardless of all considerations whether in the saving of money to the Government or otherwise. This matter seems evidently to have presented itself to the mind of the Board, and no doubt unconsciously warped its judgment and contracted its views. How far it did so can only be determined by a careful consideration of the report. Now, what facts do the Board find? 1. That the works are permanent; 2. That great and good results have been produced thereby; 3. That $350,000 will substantially complete the works; and, 4. That the works, when completed, will probably produce a channel which can be maintained of at least 25 or 26 feet in depth. In regard to the amount which will be necessary to complete the works, the Board says:

"Mr. Eads estimates the cost of doing the work thus summarily indicated at $349,641.

"The Board have carefully gone over the details of this estimate, and believe that it is substantially correct. They differ from Mr. Eads in some minor items of cost, but these differences are amply covered by the $58,273 allowed for contingencies.

"The Board is therefore of the opinion that the work indicated by Mr. Eads can probably be done for his estimate, provided no extraordinary contingencies intervene."

The Commission of 1874 estimated the cost of the works at the sum of $5,342,110. I agreed, however, to do the work for $5,250,000, thus saving to the Government $92,110 in construction. And I agreed to maintain the works for twenty years for $100,000 per annum (which maintenance the Commission had estimated at $130,000 per annum), thus saving $600,000 more. It appears, then, that $5,250,000 was a low estimate for the cost of the work. The Board (as we have seen) says $350,000 will complete the work; and it admits that only $1,686,066 has been paid on it up to this time.

The account, therefore, from the Board's own showing, stands thus:

Price to be paid for the works	$5,250,000
Paid on account to date	1,686,066
Amount unpaid	3,563,934
Required to complete the works	350,000
Surplus in the hands of the United States	$3,213,934

Reference might here again be made to my letter to the Board, from which I quote the following:

"But if the progress made by us in producing stipulated depths of channel be alone taken as the only basis for determining the proportion of the work that has thus far been completed (although such method of estimating it would seem manifestly unfair), it can be

shown that the pay received falls much below what it should be, even under such ruling.

"For instance, we were to deepen the bar from 8 feet to 30 feet, being a total deepening of 22 feet, of which 22 feet we have already accomplished 15 feet, having at present a channel depth of 23 feet. This is equal to fifteen twenty-seconds, or nearly 68 per cent. of the total depth.

Sixty eight per cent. of the price for the completed work is..	$3,570,000
Paid by the Government (to Jan. 1st)........................	1,600,000
	1,970,000
Less ten per cent. reservation..............................	197,000
Leaving unpaid and already earned...........................	$1,773,000

"If this sum were authorized to be paid at once by the Government, it would still retain $1,877,000, or $877,000 to complete the works, and $1,000,000 reserved to be paid in ten and twenty years. I will add that, if this total sum were at once paid me, it would not suffice to discharge all the debts created by me in the construction of the works."

Surely the retention by the Government of the sum of $1,877,000 would afford it ample security to cover any exigency which might arise. The conclusions of the Board upon this subject we will notice hereafter. Reference may here be made, however, to a suggestion of the Board touching the matter of future expenditures upon work at the sea ends of the jetties. It says:

"The jetties may be considered as fairly permanent, except the outer ends for a distance of about 1,500 feet. Here the chief difficulty is due to the softness of the bottom on which the jetties rest. Experience indicates that they will continue to settle, and will therefore require to be raised from time to time. When this subsidence will cease it is now impossible to predict. All the other works may be considered as fairly permanent, or can be made so. What repairs will be needed on them from time to time will be moderate in amount and easily made."

If, indeed, it be true that the sea ends of the jetties will settle, and it will become necessary to raise them from time to time, such work can readily be done without reference to the sum of $5,250,000 to be paid for the work. The act of A. D. 1875 (jetty act) reserves one million of the price, and $100,000 per annum as an independent fund for maintenance, which is sufficiently ample to cover all such contingencies.

PROBABLE RESULTS.

We now come to consider the question "what depths of channel will the works produce?" In regard to this the Board says:

"The foregoing considerations and the facts already stated under the head of results actually observed in the progress of channel de-

velopment during the last twelve months, induce us to think that if the jetties were well consolidated and raised sufficiently high to prevent leakage and overflow, a considerable increase of navigable depth would result. We can not state that, in our opinion, it is a 'probable result' that the depth of 30 feet will be attained, as assumed by Mr. Eads. What the limit will be can not be positively announced. That it may attain a depth of 25 or 26 feet is all we can venture to expect as a depth which shall permanently maintain itself; and as past experience shows annual fluctuations amounting to about two feet, a permanent channel of 25 or 26 feet will require an occasional channel of 27 or 28 feet."

RECOMMENDATIONS OF THE BOARD.

Having thus given the facts found and submitted by the Board, we come to consider its recommendations. These are, in brief, as follows: 1, That $250,000 of the 26 feet payment be advanced to me, to be expended under conditions similar to those imposed by the third section of act of June 19, A. D. 1878; and 2 (in the language of the Board), "As every additional foot in depth of channel is a benefit to commerce, we would suggest the advisability of a change in the terms of payment in the original act, so as to allow of payments for each additional foot gained instead of for every two feet, the channels and payments to be as shown in the following table:"

Present System.			System Recommended.		
Channel, feet.	Pay'ts.	Payments for 12 Months' Maintenance.	Channel, feet.	Pay'ts.	Payments for 12 Months' Maintenance.
28 x 350	$500,000	$250,000 with 6 per cent. interest.	27 x 325	$250,000	$125,000 with 6 per cent. interest.
			28 x 350	250,000	$125,000 with 6 per cent. interest.
30 x 350	500,000	$500,000 with 5 per cent. interest.	29 x 350	250,000	$250,000 with 5 per cent. interest.
			30 x 350	250,000	$250,000 with 5 per cent. interest.

In the face of the great results accomplished and about to be accomplished, and with less than one-third of the price of the works paid, the board recommends no action whatever by Congress which would really afford me the relief which my necessities demand. The report is rich in expressions of approval of the work — poor only in its recommendations. Of what avail to me would be the advance of $250,000, hampered by the condition that it be expended only on the

works? Would it serve to relieve me from the mountain of debt which I bear? Would it pay, even to a small extent, the contractors whom I have employed, and who have devoted their whole fortunes and years of labor to this great work? The liberality of this recommendation of the Board is only equaled by that of its second recommendation, which, in plain English, may be stated thus: "The works will not, we believe, produce a greater depth of channel than 26 feet. We recommend that for every additional foot *over* 26 feet secured, Mr. Eads be paid the following sums of money."

Again I call attention to the fact that the Board of A. D. 1874 (of which one of the present board was the president) recommended the improvement of the South Pass. They said in substance: This work will cost $5,342,110; it will secure a channel 25 or 26 feet in depth. This is a sufficient channel to accommodate the present and prospective wants of commerce, and the work should be done. The present Board (in effect) says: Mr. Eads has done the work contemplated by the Board of A. D. 1874; he has secured 23 feet of channel depth; the completion of the works, which are of a permanent character, will cost $350,000, and a channel will then be produced of 26 feet, which can be maintained; for this work Mr. Eads has only thus far received from the government $1,686,066, and with $3,563,934 of the agreed price still unpaid in the hands of the government, we are only willing to recommend that $250,000 more, hampered with the condition that every dollar shall be expended on the work, shall be appropriated by Congress, and provision be made that he shall receive further payments when he obtains depths which we do not believe he ever can secure.

The Board, in its report, uses the following language:

"But it should be remarked that a channel of less depth than 18 feet at South Pass was not necessary. * * * * The useful result accomplished is, therefore, a channel from 18 feet to 23 feet." In this conneetion the Board might have added that a permanent channel 18 feet in depth was worth to the government $250,000 per annum, as it cost about that amount to maintain the uncertain channel at Southwest Pass.

Particular attention is called to the following paragraph in the report:

"The Board of 1874, instituted by act of Congress to determine the best method to secure an outlet from the Mississippi River to the Gulf, either by a canal or by the improvement of one of its natural outlets, reported in favor of improvement of the South Pass at an estimated cost of $5,342,110, declaring that while its estimate was designed to cover every possible contingency of cost, it was believed the work could be done for a much less sum. No reason is known why Congress, which adopted this recommendation, should not have left the execution of the work to its own agents, except that the present contractor, Mr. James B. Eads, offered to accomplish the results contemplated by the Board without payment unless those results were

secured. It would seem, therefore, that this proposition of payments for results only influenced Congress to award the contract to Mr. Eads instead of leaving the execution of the work to its usual agents. Taking this principle of no payments except for results as the motive which governed Congress in awarding the contract to Mr. Eads, we are prepared to consider his claims to aid beyond what the original contract gives him and what the supplemental act of June 19, 1878, advances to him."

This paragraph conveys the plain inference that I have been simply executing a system of improvements originally designed and recommended by the Commission of 1874, and that the construction of the works was not put in the hands of the Engineer Corps of the army by Congress simply because I promised certain specified results on pain of non-payment. This inference is fully sustained by the conclusions of the Board and its recommendations. I am thus not only denied the right to pecuniary relief by the deductions which the Board has drawn from its premises, but the premises themselves deprive me of any consideration in connection with my appeal, of the important fact, that it was I, and not the engineers of the army, who initiated and planned the improvement which has proved so successful.

This statement of the Board and its unfair conclusions therefore, compel me in self defense, to state that I urged this plan of improvement *as the only proper one*, upon the attention of a large number of the members of the Forty-Third Congress, in May of 1873, during their visit to the mouth of the river, and that in the winter following I made a formal proposition to Congress to deepen the mouth of the Southwest Pass by the jetty system, *and offered to guarantee* its complete success, *before* any member of the Corps of Engineers (so far as I can learn) had ever expressed officially or publicly any *preference whatever* for this method of improving the mouth of the Mississippi over that of a canal, and long before the Commission of 1874 was even thought of.* Indeed, the very creation of this Commission, was the result of my proposal, and the opposition it evoked from some of the prominent engineers of the army. General Barnard, afterwards,† and the Commission after him, recommended its appli-

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* The first appropriation for improving the mouth of the river was made 42 years ago. The plan of dredging with buckets was recommended, and the plan was approved by a board of United States Engineers. In 1852, another appropriation was made, and a board composed of Captain Latimer, of the Navy, and Major Chase, General Barnard, and General Beauregard. This board recommended, *first*, the process of stirring up the bottom should be tried: *second*, if this failed, dredging by buckets should be tried; *third*, if both those modes failed, parallel jetties should be constructed "at the mouth of *Southwest Pass*, to be extended into the Gulf annually as experience should show necessary;" *fourth*, should it then be needed, lateral outlets should be closed. *Finally*, should all these methods fail, *a ship canal* might be resorted to. See Humphreys and Abbot's Report, page 486.

† General Barnard, in his minority report on the Fort St. Philip canal, dated 29th

cation to the South Pass, which location required the reduction of a shoal at the head of the pass, that has since been admitted by engineers generally, to have been a problem of greater difficulty than that at the mouth. General Barnard and the Commission simply differed with me in the selection of the pass for the application of the jetty system, and there has been nothing in the results produced, or in my studies of the subject, to alter my belief that a larger and deeper channel could have been secured at an earlier date at the Southwest Pass, and one no less permanent, than the one which has been obtained at the South Pass.

So far as the plans of construction and location of the various works are concerned at South Pass, they are my own and were not furnished or planned by the Commission. The report of the Commission and the lesser cost of improving South Pass, caused the Senate to disagree with the House, which, notwithstanding the report, had voted almost unanimously to apply the proposed system to the larger pass.

The unusual severity of those provisions of the jetty act, by which an almost entire completion of the work was really required for a total payment of less than one-third of the agreed price, can only be attributed to the hostility evinced by some of the members of the engineer corps of the army. Their arguments against the plan and their determination that this great work should not be intrusted to me, gave birth to all kinds of predictions of evil and failure. Their antagonism naturally enough alarmed Congress, and resulted, first, in the enactment of the severe provisions referred to; and, second, in requiring me to accept the South, instead of the Southwest Pass. The bill as it passed the House provided for the improvement of the Southwest Pass. In the closing hours of the session, however, the Senate committee, as advised by the Commission, substituted the South Pass, but against my own protestation and *without the advice of experts*, it insisted on my agreeing to produce at this little pass, depths and widths of channel similar to those I had proposed for a pass four times as large, or else see the execution of my project put into the hands of its opposers.

January, 1874, discusses, *first*, the method of dredging, or stirring up the bottom, and, *second*, that of jetties. With respect to dredging, and as a reason for *further consideration* and study of the means to be finally selected for surmounting the difficulties at the mouth of the river, he says: "By reference to the best authority, I have proved the adequacy of dredging operations on the bar by well-tested means, but I think there is yet room for improvement, and especially in diminishing cost." He further says of dredging, that the attainment of 20 feet depth on the bar has by no means been established to be the maximum, and adds: "As to that depth, however, we have the strongest assurances." He discusses the jetty method of improvement with great ability, but says: "The question submitted, however, is not so much, to recommend its trial (of the jetty system) as to recommend its *consideration* and that scrutiny and survey on which alone estimates can be based."

In March, 1871, the Secretary of War was requested to cause an examination and survey, with plans and estimates of cost, to be made for a ship canal to connect the river with the gulf, and to report upon the feasibility of the same. About three years later (Feb. 4, 1874), a Board consisting of seven army engineer officers reported in favor of its construction—General Barnard its president, alone dissenting. The majority of that Board and the Chief of Engineers took strong ground against the jetties, and the energy with which their opinions were maintained resulted in the passage of a bill in the House of Representatives in June, 1874, appropriating $8,000,000 with which to *commence* the construction of the canal, the cost of which was estimated at $13,000,000.* The Senate Committe rejected the canal bill, and introduced a bill to create the Commission referred to by the Board as the Commission of 1874, which Commission did not report in favor of applying the jetty system to the South Pass until January 13th, 1875.

I think the members of the Forty-Third Congress will dissent from the inference sought to be created by the Board, namely, that the method of improvement adopted by that Congress was originated by the Commission of 1874, and that but for my proposal the Engineers of the Army would have been intrusted with the building of the jetties, for the facts show that the Commission of 1874 would not have been created but for my proposal, and that if I had not made it, and urged the jetty system with all the ability I could command, the "usual agents of the Government," instead of being intrusted with this work, would, in all probability, now be digging in the sickly marshes of Louisiana the canal recommended by a prior Commission.

Of that stupendous project, General Barnard, when advocating "an open river mouth," said: "It would be a rash confidence that would anticipate a completed Fort. St. Philip canal earlier than 1884."

From those facts it is evident that if it had not been for my proposition to deepen the mouth of of the Mississippi river by the jetty system, the commerce of the vast empire which constitutes its valley, would to-day, and for years to come, be fretted and hampered by the bars at the mouth of the river, or be compelled to seek expensive and unnatural routes to the seaboard. Further comment is unnecessary.

It remains to be seen whether an American Congress is prepared to put the stamp of condemnation upon individual enterprise, and decline to act with justice and liberality toward one who, in the face of unprecedented difficulties, has secured to the Valley of the Mississippi, and to the whole country, a deep and permanent outlet from the river to the sea.

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* See Report of the Secretary of War, 1874, 1875, vol. 2, part 1, page 866.

LETTER

To the Editor of the New York "Tribune," Published April 3, 1879.

Sir,—As the *Tribune*, with its catholic spirit of liberality, has been a constant advocate of the improvement of the mouth of the Mississippi from its commencement to the present moment, I venture to ask space in its columns to correct some misstatements respecting the work and its results, made during the last few weeks by the Cincinnati *Commercial*, the Chicago *Tribune* and the Memphis *Avalanche*. I cannot be expected to reply to every petty censor in the land who chooses to belittle this important work, or to answer the personal assaults which ignorance or malice may prompt; but as persistent falsification is often accepted for the truth, I will be pardoned for exposing some of the most notable misstatements made by these papers respecting the jetties. I naturally seek to do this through the columns of a metropolitan journal whose readers are so much more numerous than those of the provincial dailies mentioned.

These papers condemn Congress for the recent advance made to me of $750,000, on the ground that I have not given an equivalent for the money. The *Commercial* says: "The whole contract was changed in the interest of the contractor," and that "the operation was one of the most impudent and shameless ever perpetrated." It says: "He succeeded in manipulating Congressmen and bringing about a change of contract increasing the liabilities of the United States $5,000,000, and so involved is this trick that the country has hardly been able to discover it." These statements are simply "impudent and shameless" falsehoods, as will be seen presently.

When the jetty bill first passed the House of Representatives, it provided for the improvement of the Southwest Pass, which was twice as wide and twice as deep as the South Pass. It was the one I wished to improve, for it was not obstructed by a bar at its upper end, as the South Pass was, and it had nearly twice as deep water on the bar at its mouth. Besides these advantages, it discharges four times as much water. There was, therefore, no reason why I could not safely guarantee to produce through its bar a channel 30 feet deep, with a bottom width of 350 feet, although this great width of 30 feet water involved the necessity of a central depth probably 10 feet greater. In

the last hours of the session, acting under the advice of the Commission of Engineers of 1874, the bill was changed by the Senate and made to apply to the South Pass, against my advice, and with my assurance that the size of channel named in the bill was so great that it could only be obtained by the dangerous experiment of directing more water into the the pass than its natural volume. This, for reasons that are well understood by hydraulic engineers, is deemed hazardous.

It was in evidence before the committees of the Senate and House, at the last session, that Gens. Barnard and Wright, and all of the seven engineers composing the Commission of 1874, thought it unwise to attempt this experiment. The works at the head of the passes now completely control the discharge of each pass, and at but little additional cost, the discharge of South Pass can be doubled or quadrupled. Its natural discharge is only about one-tenth part of the whole volume of the river. This discharge was reduced by the various other works constructed, until last year it had lost probably 10 per cent. of its volume. This has now been fully restored by recent alterations in the controlling works at the head of the pass. From these facts it must be evident that I was prepared to increase its volume to any extent, if the Government required it, and it therefore remained for Congress to determine whether it was to the interest of the United States to risk the possible injury or ultimate destruction of the good result already secured by insisting on the attempt to create a channel greater than the natural volume of the pass could produce with safety. The needs of commerce will be amply satisfied with the dimensions now fixed by law. For these reasons, the Senate committee said in its report: "The decrease of widths from those required by the act of 1875 will be as much to the interest of the Government as to that of Mr. Eads."

The question of advancing money to me beyond the requirements of the law was very carefully considered by both committees, and especially by the Senate committee. The provisions of the original act were studiously drawn to protect the Government from the very slightest possibility of paying out a dollar on this great work before its absolute success should be so far demonstrated as to give results of unquestioned commercial value fully equal to the promised payments, and also to throw upon myself and my associates every possible hazard of the undertaking. The severity of its provisions may be inferred from the fact that although the works are so nearly completed, and although a channel depth of nearly 25 feet is secured through them, under the terms of the original act we would only be entitled to-day to $1,000,000 of the agreed price for the works, or to less than one-fifth part of that price. When to this fact it is added that we undertook the deepening of this channel for $92,110 less than seven eminent engineers estimated that it would cost under the usual mode of pay-

ment; that we assumed every risk of injury to the works and failure of the plan, and that we have, even under the amended law, to create a channel four or five feet deeper than they proposed to secure with their estimate, I feel sure that all fair-minded men will, in view of the results we have accomplished, believe that we have fairly earned all the money we have yet received from the Government.

After a thorough examination of all the facts, the Senate committee in its report says: "The committee is of opinion that Mr. Eads is entitled to relief, whatever the light in which the question may be considered; whether in the light of results accomplished, proportion of work done, or money expended." The report continues: "The proposition of Mr. Eads to do the work for a sum $92,110 less than the cost of construction, as estimated by the Commission of 1874, would seem to indicate that the total price, $5,250,000, was a moderate estimate for the cost of the work. The present Board having certified that $350,000 will complete the work, it is at once apparent that but little more remains to be done, and that the work may be regarded as substantially completed."

The statement of the Cincinnati *Commercial*, that the liability of the United States has been increased $5,000,000 by the recent act, is utterly untrue. The price to be paid has not been increased a farthing. Nor has the maximum depth required by the original act been lessened. One and a half million dollars of the price still depends upon my securing a depth of 30 feet through the jetties.

Under the law, as amended, I am only to receive $3,750,000 for a channel 26 feet deep, having a bottom width of that depth 200 feet wide. Does such a sum for such a channel justify the cry of "job," which these papers are so ready to utter? It is a better channel than the one contemplated by the Commission of 1874, and yet I am to receive for it $1,592,110 less than the estimate of the Commission for a smaller one. Again, before the jetty act was passed, a bill for the construction of the Fort St. Philip canal had passed the House, which contained an appropriation of $8,000,000 with which to begin the construction of the canal. This bill would undoubtedly have passed the Senate also but for my proposition to build the jetties. When this fact is remembered, it must be evident that I have already saved the Government many million dollars that would otherwise have been expended on the canal, and that I have given relief to the commerce of the Mississippi Valley many years earlier than would otherwise have been possible. I have only received $2,500,000 on this work, while able and experienced engineers believe the canal would have cost $20,000,000, and that it would have required ten years before the first ship could have been passed through it.

One of these carping journals asserts that "vessels every week stick in the mud," in passing through the jetties. If this were true, I

might properly reply that under my grant from Congress I am not required to furnish good pilots as well as a good channel.

The following extract from the testimony of General Wright (one of the late Board), taken by the Senate committee, shows whether the channel is a good one or not:

"Q. Have you any means of estimating the advantages to commerce already attained by the condition and depth of the channel at present, as compared with the condition of the passes of the river prior to any attempt made under the jetty system?—A. The present condition is superior to any that ever existed there before, and, in my judgment, entirely sufficient for all the purposes of commerce for vessels drawing not exceeding 23 feet of water.

"Q. In other words, I understand you to say that the advantages obtained for commerce are greatly increased?—A. Yes, sir; larger vessels can pass in and out, and the channel is a good one as far as it goes—a first-rate one." (See printed testimony, pages 9 and 10.)

The declaration that vessels are constantly delayed in the jetty channel is a gross misrepresentation. The South Pass is ten miles long, and the depth through it is nowhere less than 30 feet. It is about 600 feet wide, and is in reality a magnificent natural canal. The law contemplates no work on it, for it needs none. The steamship Mikado, by bad seamanship, ran aground in it two miles below the head of the pass, on the east side of the channel. Forthwith, the journals referred to published the statement that she was aground in the jetties. About the 1st of March the Inman steamer City of Limerick, drawing 23½ feet, bound for Liverpool, came to anchor at Port Eads, some defect in her machinery having been discovered, whereupon one of the truthful journals promptly informs the public that the City of Limerick was "stuck in the mud in the jetties." I believe there has not been a single vessel delayed in its passage through the jetties in the last four months. Two or three in that time have been detained for a few hours at the head of the pass, where the depth is probably a foot less.

The Chicago *Tribune*, within a fortnight, contained the following statement: "During the war the steamship Mississippi, lost in the Port Hudson fight, came in over the bar drawing 21 feet, and the Richmond and Hartford, drawing about the same, frequently crossed it." A similar statement was made recently in the *Commercial*. Being anxious to know the truth of this statement, I addressed a note of inquiry to the Hon. Secretary of the Navy, and I have his reply, dated 24th instant, before me, from which I make the following extract. Referring to the United States steamer Hartford, he says: "An examination of the log-book shows her draft as follows: 'March 2, 1862, 16 ft. 4 aft, 10 ft. 6 forward.... March 10, began working for the bar; 12, sent four mushrooms and chains, six stone anchors, and one iron buoy ashore; 13, crossed the bar.'" This record shows how perfectly reckless these journals are in making their statements.

The draft of the Mississippi could not be ascertained, but I am informed that the Pensacola grounded on the bar in 15 feet of water, drawing but 16 ft. 3, on the 24th of March, 1862.

A piece of worm-eaten wood, alleged to have been taken from the jetties, has been shown to these guardians of the public weal, and it seems to have created the greatest alarm. Numerous essays upon the destructive character of the teredo have ensued. None of these journals, however, has published the following statement on this point, made by the five distinguished engineers of the army who were required by Congress to report upon the jetties last winter:

> "Experience here shows that for about 1,700 feet inwards from the jetty ends the teredo destroys rapidly all exposed wood (including in this term the willows of the mattresses) lying more than four or five feet below the surface of the water. Evidence enough of its attacks upon piles and willows exists. But the teredo does not attack wood where the free access of sea water is impeded. Those portions of a stick buried in mud or sand, or packed around with mud or sand, are secure. We have no reason to believe that the teredo has penetrated or can penetrate far into the interior of the mattress courses; we have pretty good reason to believe that the foundation mattresses are and will remain secure; and probably also the bulk of the interior of the masses of willow work."

Many important sea works are in existence in Holland and elsewhere, in which willows constitute large portions of the work, but no such disastrous results as are predicted have yet occurred in any of them, so far as I can learn. But should the sea-ends of our works be eaten up by the teredo, it may comfort these nervous newspapers to learn that the law provides that a million dollars of my compensation shall be withheld as a guarantee that I will maintain the integrity of the jetties against all enemies, worms included, after their completion, for $100,000 per annum for twenty years. Hence, if the worms do not get willows enough, the million dollars reserved must, greatly to my sorrow, supply the deficiency.

In addition to the distress which the worms have given these journalists, they are sorely troubled about the re-formation of the bar in front of the jetties. One of them declares that "Captain Brown's report shows the average fill from June, 1876, to June, 1877, from the ends of the jetties out one mile and a quarter, is 11 feet and 7 inches." It is needless to say that Captain Brown's report shows no such thing. If it did, the late Board could not have said, as it did in its report:

> "The actual results, therefore, so far as we know them, do not justify the predictions of accelerated bar advance. On the contrary, they show a disappearance of bar material from the front of the jetties."

Captain Howell's report of 1877 is quoted to create the impression that the bar is forming 25,000 feet out from the jetties, al-

though no survey has been made in front of the South Pass since 1875 (the year the jetty act was passed) except those by Captain Brown and the Coast Survey, and these prove that the sea bottom is undoubtedly deeper since the construction of the jetties than before. Captain Howell likewise predicted that the "jetties would have to be built further and further out, not annually, but steadily every day of each year, to keep pace with the river deposit into the Gulf." This we have not yet found necessary to do, the jetties being now about three hundred feet shorter than they were originally designed. He has simply established a new location for the anticipated bar, and the respectable distance of 25,000 feet (or five miles) from the jetties, where it is alleged to be re-forming, should prevent undue anxiety on the subject for a few centuries to come.

The latest official report of the depth of our channel is as follows:

"U. S. ENGINEER'S OFFICE, SOUTH PASS, LA.,
March 15, 1879.

"*Editor New Orleans Times:*

"Over South Pass bar the depth of water at average flood tide, March 14, 1879, was 24.8 feet. The least width for this depth was 80 feet.

"At high water of the day the least depth was 25.4, and at low water 23.8 feet.

"At head of passes, March 3, the least depth of channel at average flood tide was 23 feet, at high tide 24.5 feet, and at low tide 23.3 feet.

"I certify that the above is a correct statement.

"M. R. BROWN,
"Captain of Engineers, U. S. A.

"Published by order of the Hon. Secretary of War."

The Hon. C. P. Patterson, Superintendent United States Coast Survey, informs me that the depth over the bar at Sandy Hook at low tide is but 23 feet; it therefore appears that while the enemies and opposers of the jetties have kept up a persistent and, in many instances, a most unscrupulous warfare upon the undertaking, the work has gone steadily on until it is almost completed, and already it has caused the current of the river to deepen a channel through a bar in the Gulf two miles and a quarter in extent, from a depth of about seven feet at low tide to a depth eight-tenths of a foot greater than that which exists at low tide in the chief entrance to New York harbor.

JAS. B. EADS.

St. Louis, Mo., March 27, 1879.

PHYSICS AND HYDRAULICS OF THE MISSISSIPPI RIVER.

Review of the Report of U. S. Levee Commission of 1875.

In 1875 the Commission of Engineers authorized by the Forty-Third Congress to report a permanent plan for the reclamation of the alluvial lands of the Mississippi River, submitted their report to the President. The plan recommended contemplates raising the present levees from 3 to 11 feet above the great flood of 1858, and involves an estimated cost of $46,000,000.

"The outlet system," approved by the Commission, is thus briefly and clearly explained in the report:

"The plan consists in abstracting from the river, and conducting by separate channels to the Gulf, such a volume of the flood discharge as shall be sufficient to bring down the flood-level to a height easily under control by levees."

Referring to Bayou Atchafalaya, the report says:

"This outlet it has been proposed to close, and we desire to place on record our decided disapproval of any such scheme."

The re-opening of Bayou Plaquemine, under certain conditions, is recommended.

The following refers to Bayou Lafourche:

"Its closure was recently recommended by a majority in a board of State engineers, in our judgment unadvisedly."

The Commission thus express their regret that the artificial depletion of the river is not likewise practicable:

"In fine, then, this commission is forced unwillingly to the conclusion that no assistance in reclaiming the alluvial region from overflow can judiciously be anticipated from artificial outlets. They are correct in theory, but no advantageous sites for their construction exist."

Believing that depletion will permanently *lower* the height of the floods, the Commission of course infer that the closure of the numerous and extensive gaps now existing in the levees, and which constitute so many outlets in floodtime, will necessarily *raise* the flood-line permanently, and hence necessitate a corresponding eleva-

tion of the levees. The extra heights of these the Commission estimate as follows:

"Near the mouth of the Ohio, the levees should be made about three feet above the actual high-water flood of 1858. * * * The height above this level should be gradually increased to about seven feet at Osceola; thence to Helena the latter height should be maintained; thence to Island 71 the height should be gradually increased to ten feet; thence to the vicinity of Napoleon it may be gradually reduced to eight feet; thence to Lake Providence it must be gradually increased to eleven feet; thence to the mouth of the Yazoo, it may be gradually reduced to six feet, and it should thus be maintained to Natchez; thence to Red River Landing it must be gradually increased to seven feet; thence to Baton Rouge it may be gradually reduced to five feet; thence to Donaldsonville this height must be maintained."

The report, therefore, declares in effect: If we *reduce* the volume of water in the channel, a permanent *lowering* of the flood-line will result. If we *increase* the volume, a permanent *elevation* of this line will occur.

The non-professional reader will fully comprehend the effect of elevating or lowering the slope of the flood-line if he will bear constantly in mind that the lower end of this slope is unalterably fixed by the Gulf of Mexico. Hence, *if the slope be raised at all it must come higher up on the levees.*

An examination of the map of the mouths of the river will show that precisely the opposite effect to that anticipated by the Commission has occurred in each one of its several passes and bayous. *The less the volume* the shorter is the outlet from the river to the sea, and consequently *the steeper is its slope* in every instance.

The river throughout the 1,100 miles of its course below the Ozark spur, near Cape Girardeau, likewise presents successive phenomea in direct conflict with the theory of the report. As we descend the river through its alluvial basin, the surface-slope of its flood-line becomes less and less steep below each succeeding tributary, and its volume becomes concentrated into one uniform channel, with increased depth and diminished width. At Cairo this slope is about 6 inches to the mile; at Vicksburg, about 4 inches; at Red River, about 3 inches; while below New Orleans it is reduced to less than 1½ inches to the mile. Thus the main stream and each of its active passes and bayous teach us, that in proportion as the volume of discharge is diminished, the flood-slope of each is permanently increased.

I believe every other sediment-bearing river in the world through its alluvial basin, gives similar evidence of its obedience to the same law, and exhibits results the very reverse of those anticipated by the Commission.

The recommendations of the report seem likewise at variance with the recognized principles of hydrodynamics.

The flow of a river is partially checked by the bends and irregular-

ities of its channel, but the chief element retarding its velocity is the friction of the bed. Gravity is the force that overcomes this friction. A pipe four feet in diameter has but four times the circumference or frictional surface of one only a foot in diameter, but will contain sixteen times as much water. Hence the frictional surface retarding the flow in the larger pipe, will be only one-fourth as great, in proportion to volume, as that in the smaller one. Therefore, to create the same velocity in each pipe, we must apply more force (gravity) to the water in the smaller one. This is done by giving it a steeper slope. Nature has done this in adjusting the slope of the main stream and that of each of its outlets to the sea, in proportion to its volume of discharge. These slopes all prove that each is obedient to this inexorable law.

The report has received the following indorsement from Gen. A. A. Humphreys, Chief of Engineers, U. S. A.:

"I beg leave to say that the views, plan and recommendations of this board meet with my full concurrence."

The public will naturally infer that the reasons which induced the highest engineer officer of the army and the members of the Commission to recommend a plan so apparently in conflict with the phenomena of the river and with the principles of dydrodynamics, must rest upon facts so thoroughly established as to defy successful denial.

A MYSTERIOUS CLAY.

The report says: "It is asserted in the most confident manner that the river is flowing in a bed composed of its own deposit, with dimensions regulated in accordance with its own needs; and hence the increased velocity, resulting from the confinement of its flood volume between levees, will rapidly excavate its bed to a correspondingly greater depth, thus avoiding any permanent increase in the high-water mark.

"This reasoning, if true, would establish conditions singularly fortunate for the levee system; but, unluckily the wish has been father to the thought. Uncompromising facts show that the premises and conclusions are both erroneous for the lower Mississippi. Very numerous soundings, with leads adapted to bring up samples of the bottom, were made by the Mississippi Delta Survey throughout the whole region between Cairo and the Gulf. They showed conclusively that the *real bed*, upon which rest the shifting sand-bars and mud-banks made by local causes, is always found in a stratum of hard blue clay, quite unlike the present deposits of the river. It is similar to that forming the bed of the Atchafalaya at its efflux, and, as is well known, resists the action of the strong current almost like marble. Clearly, then, the bed of the Mississippi cannot yield, and if the velocity be increased sufficiently to compel an enlargement of the channel, it must be made by an increased caving of the banks, an effect which it is not quite so agreeable to contemplate."

This extract, I believe, contains all of the "uncompromising facts"

relied upon, for the assumption that natural laws will be reversed if the proposed plan be carried into effect. The report virtually admits that but for the existence of a peculiar blue clay, these "singularly fortunate conditions for the levee system" would be established. That is, that the extra hight proposed for the levees would be unnecessary.

The present Chief of Engineers, and one of the members of this Commission were the authors of the Delta Survey Report in which the existence of this peculiar clay was first asserted as a *positive fact*, and it is possible that "the wish has been father to the thought" expressed in the above extract. The reader should remember, however, that *assertion* is not *evidence*. When we divest the question of the dogmatism which envelops it in this report and in that of the Delta Survey, it will be seen that the existence of this peculiar clay is altogether mythical, and that it *is not* established by a mass of "uncompromising facts."

Blue clay is found in the bottom and banks of the Mississippi at various localities, from the head of its alluvial basin to the Gulf of Mexico. The exposure of the various strata in its banks above low-water mark, and the intersection of these strata in various artificial excavations; their rapid destruction by the river current where the main stream forsakes its old channel and plows out a new bed through one of its many characteristic cut-offs; the penetration of several of these strata by the artesian well at New Orleans before it had reached a depth equal to the present bed of the river at that place, and through which strata the river has evidently cut its way, all prove that the ordinary blue clay of the river will not resist the incessant action of the current.

The Chief of Engineers, in one of his numerous papers, in 1874, against the jetty improvement of the mouth of the Mississippi, refers to this invulnerable clay as existing in a shoal below Bonnet Carre crevasse, where it is declared by him to constitute a bar about 30 feet higher than the bottom of the river above the crevasse. The Commission thus speak of this shoal:

"The truth is, there is a natural contraction in the channel at this point, which has remained unchanged for at least a quarter of a century. * * * To put this matter beyond cavil, a re-sounding of the old lines, as nearly as the want of exact bench marks would permit, was made for the Commission by Mr. G. W. R. Bayley, Civil Engineer."

We thus have one definitely fixed location in the river, and I believe the only one definitely stated, where this clay can be found according to the testimony of those who declare that it does really exist.

The only part, however, of Mr. Bayley's testimony relative to this mysterious clay which these parties accept, is his measurements of

the size of the channel, and these they misconstrue (as I will hereafter explain), to support their theory that a crevasse will not cause a deposit below it. They fail to state that their witness positively declares in his report that his sounding-lead sank from 12 to 24 inches deep into this shoal, which the Chief of Engineers styles a "hard blue clay of older formation." Their eminent witness, indeed, absolutely ridicules the idea of the existence of such clay there, or anywhere else in the bed of the river.

A reference to the Delta Survey report will show that the only positive evidence of the existence of this mysterious clay was obtained from its "numerous soundings," which are referred to in the above extract. So far as I know, neither the Chief of Engineers nor the Commission claims to possess any other real evidence of its existence.

I have myself sounded almost every bend in the river from St. Louis to New Orleans, and have been on the river bottom in the diving-bell in some part or other of every fifty miles of that distance, yet I have never met with any clay more unyielding than the common blue clay of its bed and banks.

The supposed invulnerability of a clay that is proof against everything but the sounding-lead is therefore seen to be the sole basis of a theory in direct conflict with natural laws, and is made the only warrant for positive official declarations which are disproved by observation and experience; while the assumption that it "resists the action of the strong current almost like marble" can not be reconciled with the fact that in the very "numerous soundings" referred to it has readily yielded samples of its substance to the sounding-lead; nor with the still more stubborn fact that the plummet of Mr. Bayley, the Commission's own witness, sank from one to two feet deep into the river bottom, where this peculiar clay is positively declared by the Delta Survey report, by the Chief of Engineers, and by the report of this Commission also, to constitute a permanent bar or contraction in the bed of the river.

WHY THE LEVEES MUST BE RAISED.

The Commission, being satisfied that this paradoxical clay which is invulnerable to everything except the persuasive tallow of the sounding-lead, is a reality, assert that "the bed of the Mississippi can not yield." Hence there can be no *deepening;* and as caving banks are "not quite so agreeable to contemplate," they are excluded from the proposed plan, and hence there can be no *widening* of the river. We are therefore told, "in fine," that "if we guard against these crevasses by raising and strengthening our levees, an elevation of the high-water mark exactly proportional to the increased volume will be sure to occur."

The reader will see that the question is, by these "uncompromising facts," greatly simplified, and he is therefore prepared to comprehend the following profound proposition, which succeeds the last question, and by which the problem has been finally solved:

"To contain a quart of water a vessel must have exactly the requisite number of cubic inches; and a like principle applies with equal force to water in motion."

Evidently if the quart measure can not be deepened nor widened, and yet must receive more water, its sides must be raised, and thus we have the principle stated by which the Commission estimated the precise number of feet above the flood line of 1858 that are required, by the levees, if we expect them to receive all of the flood-water within them; because "a like principle applies with equal force to water in motion."

SOLVING A PROBLEM IN HYDRODYNAMICS BY MENSURATION ALONE.

Impressed with the immutable truth of the quart proposition, these investigators have clearly been misled into attempting to solve their problem by the "like principle;" but unfortunately the principle involved in the number of cubic inches in the quart is one relating to *space* alone, and "a like principle" cannot apply "with equal force to water in motion," because this goes still deeper into the realm of mathematics, and involves two other principles, namely, *time* (or velocity) and *force* (or gravity), neither of which can be investigated by geometry, and either of which must greatly modify the question of *space*, or channel capacity. The enormous elevation of flood-line predicted by the report proves that neither of these two principles was considered; but believing "an elevation of the high-water mark exactly proportional to the increased volume will be sure to occur," the question was treated simply as a problem in mensuration. In other words, the enormous estimate of $46,000,000 is submitted to Congress on the assumed solution of a problem in *dynamics*, in which but one of the three essential elements (space) was considered, and hence it is without any value whatever.

Let us, however, concede for the moment that the *bottom* of the river *will not* be deepened by the increased forces due to the increased volume which the levees will concentrate within its bed. We have abundant evidence that the *banks* are vulnerable, consequently there is nothing to prevent the *widening* of the river bed when its volume of water is increased. This must inevitably occur. As the average high-water section of the river below its lowest tributary is about 200,000 square feet, with a depth of about 100 feet, a widening of about 300 feet would be sufficient to accommodate the extra 10 feet of height which the Commission assume would occur by the completion of the

levees. This widening would be a matter less serious, than what would certainly happen if their theory be correct. For if the flood slope be steepened 8 or 10 feet, it must be evident that, unless some other reversal of a natural law occurs, this increase of elevation (if it did happen), would greatly increase the current to which they attribute the caving.

THE OUTLET SYSTEM.

Let us now examine the reasons given in the report for assuming that the depletion of the river by outlets will permanently lower its flood line. The report says:

"This plan [abstracting from the river by outlets] has been stoutly opposed by certain writers of ability upon the ground that reducing the flood volume will produce deposits in the channel below the outlet, and will thus ultimately raise instead of lowering the height of the floods. This argument, theoretically, is only tenable upon the assumption that the river water is always charged with sedimentary matter to its maximum supporting capacity, an assumption which has been shown by three years of accurate daily observations at Carrollton and Columbus to be utterly unfounded. Indeed, it often happened that the amount of sedimentary matter per cubic foot of water was greater in low than in high stages of the river, and never was there any fixed relation between these quantities. In other words, Mississippi river water is undercharged with earthy matter, and therefore no reasonable reduction of its flood velocity by an outlet will produce a deposit in the bed below."

It will be observed from this extract that the conclusions of the Commission are based upon two theories originally advanced in the Delta Survey report, viz: 1st, that there is no relation between the velocity of the current and the quantity of sediment carried in suspension by the water; and 2nd, that Mississippi river water is always *undercharged* with earthy matter.

RELATION BETWEEN VELOCITY OF CURRENT AND QUANTITY OF SUSPENDED SEDIMENT.

In support of the first, the Chief of Engineers, in one of his several jetty papers in 1874, referred to these observations at Columbus and Carrollton, which were so convincing to him that he then declared it was "unnecessary to pursue the subject further."

In answer to this reference I replied in 1874, that the quantity of matter held in suspension is modified by the *depth* of the stream, and that the element of depth was totally ignored in these observations. Hence they are unintelligible, and in spite of their accuracy, which I never doubted, they are without value. I also, in 1874, pointed out the axiom that relation must exist between *cause* and *effect*, and as a

corollary of this truism, that relation must exist between their respective values or quantities; and as the current is unquestionably the *cause*, and the suspension of the sediment the *effect*, it follows that to declare that no relation exists between their values (or the quantity of sediment suspended by a given velocity), is to assert that no relation exists between cause and effect. One would naturally suppose, in the face of so unanswerable a proposition as this, that it would be "unnecessary to pursue the subject further."

The Chief of Engineers, however, in one of his four jetty papers, published in his recent official report (1875), returns to the subject, and reiterates the Delta Survey theory more emphatically than ever. But he advances no new proof, and the "long series of exact measurements at Columbus and Carrollton" alone, are still deemed so conclusive on the subject that he now declares "it will not be considered again;" from which I infer that the proof in support of his proposition is exhausted. The fact that in these "exact measurements" the element of *depth* was totally neglected, although exposed eighteen months ago, is treated with perfect silence, like the fact of Mr. Bayley's sounding-lead sinking from 12 to 24 inches into the "hard blue clay of older formation" at Bonnet Carre. Facts which cannot be answered must of course be ignored.

To understand the bearing which the neglected element of *depth* would have upon these "exact measurements" the reader should remember that it matters not by what occult mode soever the water acts upon the particles suspended, *the elevation of any matter in the current, if heavier than the water, can only be the result of an equivalent force expended in raising it,* just as the lifting of it from the river bottom would be if done by a steam engine. In this case, the force is the fall of a certain quantity of water from a higher to a lower level. In the other case, it would be the consumption of a certain quantity of coal. In either case, a given *force* can only raise a certain weight through a certain *space* in a certain *time*. It is simply impossible for the given force to raise the same weight through *twice* the space in the same time.

To raise a given weight of sediment through a given depth of water in a given time, must involve the expenditure of twice the amount of force that would be necessary to raise that weight through half that depth in the same time; and as force, depth, and velocity do not increase in the same ratio, it is evident that the depth, at any given locality, must modify the quantity of sediment which any given rate of current can lift from the bottom. Consequently, unless we correct the results of the velocity and sedimentary measurements of the Delta Survey at Columbus and Carrollton by the varying depths occurring when they were taken, these "exact measurements" actually prove nothing. Unfortunately, this correction cannot be made now. The rise and fall of the river at Columbus is over 50 feet, and

no account whatever is made of this fact in connection with these measurements. A record of the surface heights of the water at certain localities, gives no accurate indication of the alterations in depth, because the bed in all alluvial streams at various localities, deepens as the water rises, and fills up or elevates itself as the water falls. This is notably the case between the piers of the St. Louis bridge.

It does not follow, however, nor did I ever assert, that the normal quantity of sediment due to a given velocity is *always* present. These proportions must necessarily change with the inconstancy of the river volume, and the inequalities in the depth, size and form of its channel, and likewise from the fact that caving of the banks generally occurs with a reduced current, while the river is falling, because the supporting pressure of the flood-water against the saturated banks is then withdrawn. Observations immediately below where the banks are caving, would doubtless show the water to be overcharged with sediment.

An experience of nearly forty years teaches me that the Mississippi river water, throughout its alluvial basin, is constantly varying the proportions of its suspended matter, in accordance with the constant alterations of velocity in its current and its depth. At one locality and moment the water may be overloaded, and then depostion will immediately begin, and continue until the normal quantity only remains. The water thus relieved of a part of its load, when again quickened as it flows onward by some contraction in the channel or other cause, at once attacks the bed of the river, to recover the quantity due to such increased velocity.

Blue clay and gravel which are frequently found in the bed of the river, while not invulnerable to the action of the current, yield less readily to the river forces than other alluvions, and if the current be accelerated where either of these constitute the bed, the water must necessarily recover its normal charge less rapidly, and show, at certain stages below them, an undercharge of sediment. The bed, a few miles above Columbus, is composed almost wholly of gravel, cemented into considerable masses with iron rust or oxide. I know this fact, for I have walked from side to side of the river bed at that locality over more than 1,000 acres of this material, under the shelter of the diving-bell, in search of the wreck of a steamboat, whose cargo and engine I recovered.

The Chief of Engineers declares that these exact measurements "show that the current of the Mississippi river, when most feeble, can carry in suspension the greatest quantity of suspended earthy mater found in it, to the same extent that it can carry the least quantity found in it."

The law of the conservation of matter and the correlation of forces is declared by Faraday to be "the highest law in physical science which our faculties permit us to perceive." If this declaration of the

Chief of Engineers be true, it simply means that nature has excepted the Mississippi river from this great law, and that the atoms composing the countless tons of sediment which it is constantly bearing to the sea, unlike those which arrange themselves in such exquisite beauty in the snowflake, or those which constitute the majestic planet, are borne onward here by the vast forces of the river, without order and without law.

This statement is in keeping, however, with the treatment proposed for the river, whose sediment bearing features and alluvial bed, despite the facts which are presented by the stream at every turn, are practically ignored. If its waters were pure as crystal, and its bed from Cairo to the Balize were of granite, the proposed plan might be justified. We know that depletion by an outlet at Bonnet Carre would not then produce deposits in its channel below, and that its bed could not then yield. The river is, therefore, really treated as a crystal stream, flowing in a rock-lined channel, because if its water is always undercharged, as these gentlemen declare it to be, they are safe in saying that " no reasonable reduction of its flood velocity by an outlet will produce a deposit in the bed below." So, in their opinion, the sedimentary character of the river evidently makes no difference. The great fact is lost sight of, that the current of the mighty stream is burdened with the detritus of a continent, which the rains and snows are leveling down and pouring into its grand trunk for transportation to the sea. No note is taken of the daily evidence that it scours out increased room for itself whenever its current is accelerated, and that its deposits are everywhere found where its current is at all retarded. If the water were really "undercharged," it would be perfectly easy to maintain a dredged channel through any one of its shoals, whereas the efforts of the Government to do this have invariably failed. The increased capacity of channel made by the dredge is greater than the river needs for itself, and consequently causes its current to slacken in the artificial enlargement, and to drop its extra burden of sediment there to obliterate the work of the dredge and recover its natural current.

THE UNDERCHARGED THEORY DISPROVED BY FACTS.

The shoal below Bonnet Carre crevasse was in 1874 cited by me to prove that if the current be checked by the depletion of the river by a crevasse, deposition of sediment will occur below the crevasse, because the slackening of the current caused by the channel below being then too large for the diminished needs of the river, would cause the water to deposit part of its sediment, and thus raise the river bottom below the crevasse, until the natural current was restored by the contraction. The Commission reiterates substantially

what was asserted of this shoal by the Delta Survey Report, and by the Chief of Engineers, in 1874.

It declares that the supposition of its being a result of the crevasse "is an error of fact." It says: "The mistake has been caused by the discovery from soundings made *after the crevasses have ceased to flow*, that the channel below is smaller than that above, and it has been *assumed* that the difference is due to the crevasse."

Three crevasses have occurred at this point in the last twenty-five or twenty-six years. Now, as no measurements were taken *before* each occurred, it does seem like an *assumption*, quite as great on the part of the Chief of Engineers, to assert in the most positive manner that the shoal below Bonnet Carre crevasse *always* existed there. Yet we are assured by the Chief of Engineers that the subject was "carefully investigated," and that "it was found there had been no deposit whatever below Bonnet Carre crevasse, and that the bottom of the river there was of hard blue clay of older formation than alluvion, and that the cross-section had unquestionably remained unchanged." These statements are made in the absence of all measurements *before* the crevasse occurred, and, therefore, in the absence of any *positive* proof of the fact asserted.

The Commission publish tables of several measurements of the river section at this locality, made by Humphreys and Abbot, Forshey, Ellet and Bayley, and declare that "the surprising accordance" in them "puts this vexed question forever at rest," as if, forsooth, they should not accord when each measurement was made under similar conditions.

While we have good presumptive evidence that this shoal is really a deposit, the positive proof of the fact, namely, measurements of the river prior to these crevasses, is lacking. But fortunately, Mr. Marindin, Assistant United States Coast Survey, now effectually "puts this vexed question forever at rest." In 1838, Capt. Talcott surveyed the Mississippi above the head of the passes. Since that time Cubitt's crevasse has occurred, and Mr. Marindin's measurements, made last year, show that the bottom of the river below the crevasse has been raised from ten to twelve feet across its entire bed, and its channel capacity has been reduced at least one-fourth. Where Talcott found an average of over forty feet, scarcely thirty feet in depth now exists. This fact is in reality an "uncompromising" one, and it is very damaging to the positive official statements of the Chief of Engineers, and it completely upsets the "undercharged" theory of the Delta Survey.

In spite of these theories and assertions, we now *know* that shoals are produced below crevasses, and we have good reasons to believe that the one below Bonnet Carre crevasse is such a deposit. Mr. Bayley's report on it, taken in connection with the facts at Cubitt's crevasse, leaves no reasonable ground to doubt that it is a recent de-

posit, caused by the last crevasse, and that it will disappear when the crevasse is closed.

The deposits below these crevasses show that the seemingly simple question whether the velocity of current has any relation to quantity of sediment carried in suspension, is one full of the deepest interest to the people of the United States, for on it must not only essentially depend the success of the plan to be adopted for the permanent protection of one of the most valuable alluvial regions in the world, but likewise the success of all attempts to improve the most magnificent highway on the face of the earth—one constituting the only natural outlet of more than half the entire available territory of the nation, and which alone is capable of sustaining four hundred millions of people. Attempts to improve the river predicated on the untenable theories advanced years ago in the Delta Survey Report, and which have been so dogmatically maintained by the Chief of Engineers ever since, must inevitably result in failure. They are now re-affirmed by this Commission, whose president, General G. K. Warren, U. S. Engineers, assures his chief that "the foundation of the report of the Commission rests upon your invaluable surveys and investigations, which, begun in 1850 and continued till 1861, are contained in the great work, 'The Physics and Hydraulics of the Mississippi River.'"

If the theories "in the great work" be abandoned, and a system based upon observed facts and natural laws be adopted, it will certainly secure the permanent protection of the alluvial basin with one-quarter of the money estimated. If the correction of the river channel be included (as it should be) in such system, the portion of the basin above Red River can be reclaimed by permanently lowering the flood-line to such a level as to make levees on that part of the river unnecessary, while the closure of the outlets, which the report insists on keeping open, will greatly lessen the necessary height of the levees below Red River.

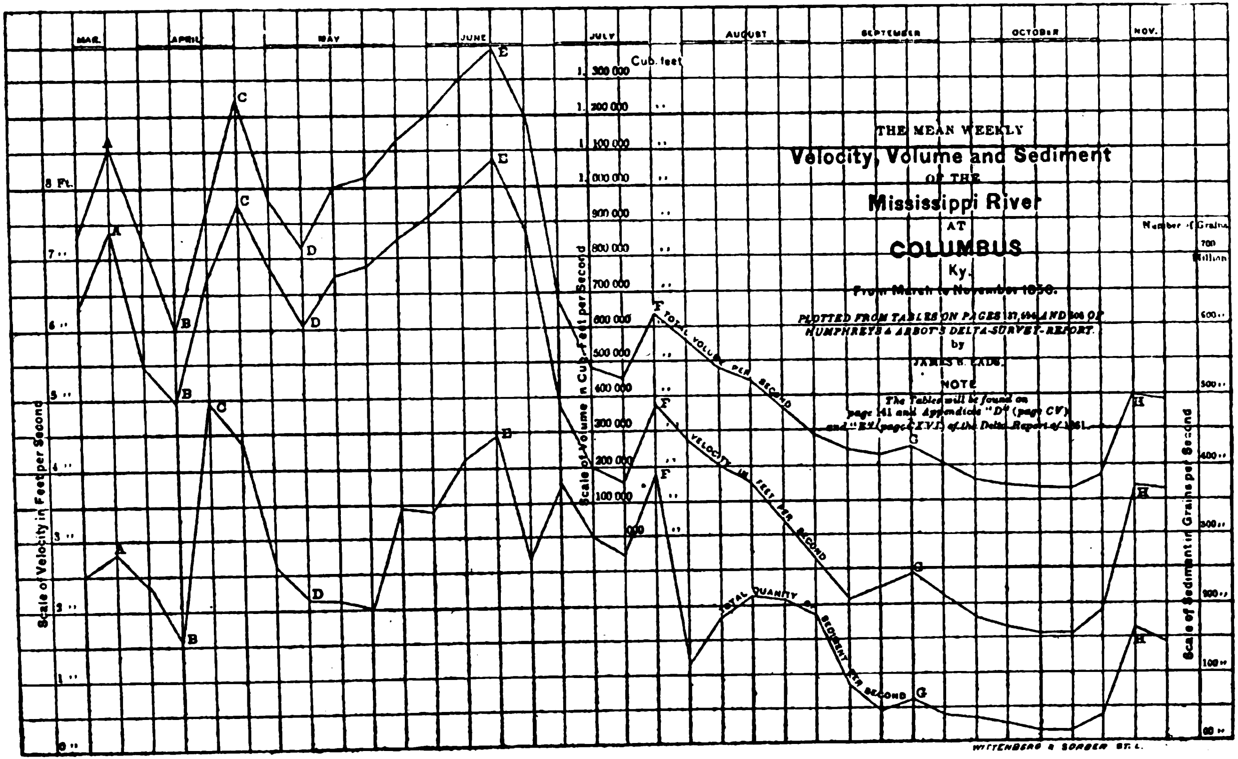
THE CLOSURE OF OUTLETS WILL LOWER THE FLOOD-LINE.

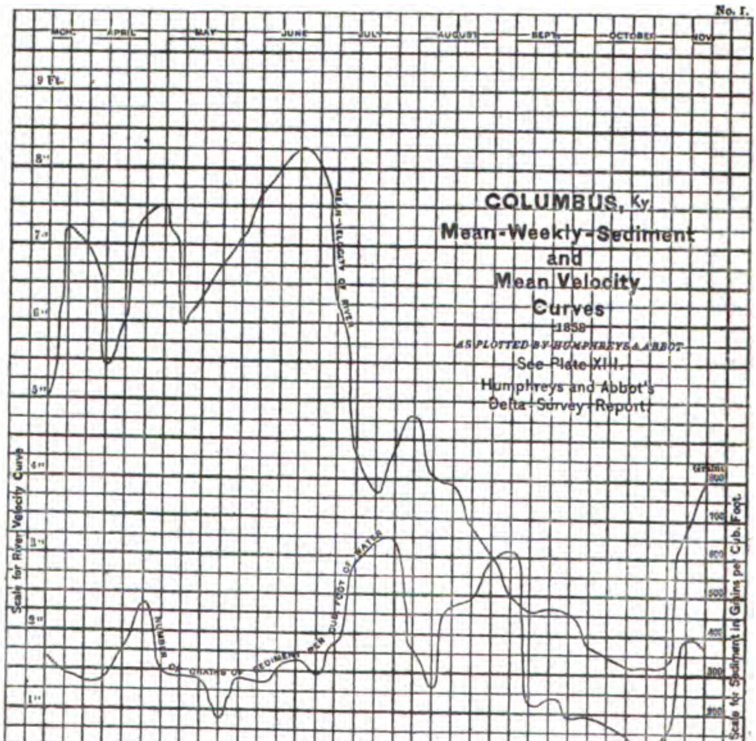
The following diagram (Fig. 1) approximately represents the mouths of the Mississippi.

At the head of the passes the flood-line of the river is about 36 inches above the medium Gulf level.* The South Pass, being twelve miles in length, has consequently a slope of three inches to the mile. The Southwest Pass is seventeen miles long, and, having the same fall (thirty six inches) as the South Pass, has a slope of two and two-seventeenths inches to the mile. Why is one so much steeper than

* The river slopes are only approximately stated. Without being perfectly accurate, they are sufficiently so for illustration.

No. 2.


THE MEAN WEEKLY
Velocity, Volume and Sediment
OF THE
Mississippi River
AT
COLUMBUS
Ky.
From March to November
HUMPHREYS & ABBOT'S DELTA-SURVEY-REPORT.
by
JAMES B. EADS.
NOTE
The Tables will be found on
MAR.
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOV.
Scale of Velocity in Feet per Second
Scale of Volume in Cub. Feet per Second
Scale of Sediment in Grains per Second
Cub. feet
TOTAL VOLUME PER SECOND
VELOCITY IN FEET PER SECOND
TOTAL QUANTITY OF SEDIMENT PER SECOND
WITTENBERG & SORBER ST. L.



No. I.
MCH.
APRIL
MAY
JUNE
JULY
AUGUST
SEPT.
OCTOBER
NOV.
9 Ft.
8 "
7 "
6 "
5 "
4 "
3 "
2 "
1 "
0 "
COLUMBUS, Ky.
Mean-Weekly-Sediment
and
Mean Velocity
Curves
1858
AS PLOTTED BY HUMPHREYS & ABBOT
See Plate XIII.
Humphreys and Abbot's
Delta Survey Report.
MEAN VELOCITY OF RIVER
NUMBER OF GRAINS OF SEDIMENT PER CUB. FOOT OF WATER
Scale for River Velocity Curve
Scale for Sediment in Grains per Cub. Foot.
Grains
800
700
600
500
400
300
200
100
00
WITTENBERG & SORBER ST. L.

the other, and why are both so much steeper than the main river? The latter rises at New Orleans about fifteen feet above the level of the Gulf, or 144 inches above the level of the flood-line at the head of the passes. From this latter point to New Orleans the distance is about one hundred miles, which, divided into 144 inches, gives a slope of less than one and a half inches to the mile. Nature has fixed these different slopes in obedience to the immutable law which I explained in the first part of this review. If we compare these slopes with the quantity of water carried through the channel of each conduit, we find that the steepest one, namely, the South Pass, has the smallest volume. It is only equal to one-twelfth of the main river, while it has more than double its slope.

The volume of the Southwest Pass is only equal to one-third, while its slope is 47 per cent. greater than that of the main river. Each one of the many outlets of the river presents the same phenomenon. The smaller the volume, the steeper is the slope. If an apparent exception be shown, it will be found that such outlet is gradually filling up in the effort to increase its slope. Bayou Lafourche is an instance of this. Suppose a horizontal line from A to B (figure 2), 9½ inches long, is drawn to represent the mean level of the Gulf, and a line from A to C, one inch long, to represent the slope of the South Pass, the end at C being ¼ inch from the line A B. From C draw a line to D to represent the slope of the river from the head of the passes to New Orleans, this line being 8½ times as long as A. C, and the end at D being an inch and a quarter distant from the line A B. The line A C D, will represent the slope of the river from the mouth of the South Pass to New Orleans in flood time, A being the mouth of the pass, C its head, and D New Orleans. Now, suppose the two grand outlets or passes on the right and left of the South Pass were closed in such manner as to direct the entire river gradually through the South Pass, the temporary effect would be just what the Commission suppose would be a permanent one. The surface of the water would be raised at the entrance of the South Pass in proportion to the rapidity with which the other two passes were closed. This elevation would increase the current through the South Pass, and enlarge it until it would finally receive the whole river, just as an excess of current has enlarged scores of cut-offs, which to-day constitute the main channel of the river. The excessive current could only last as long as this temporary elevation of surface would be maintained at the entrance of the pass, and as the enlargement progresses it would become more and more impossible to maintain this elevation.

If the entire river were thus discharged through the South Pass, it would ultimately assume a uniform section and slope from the Gulf to New Orleans. As the natural slope of the main river is 1.44 inches to the mile, while flowing in a single channel it would take that slope from the Gulf to New Orleans.

Could the hump seen in the grade line A C D possibly remain at C, the former head of the pass, and the entire river continue to maintain beyond it a slope adjusted by nature for but one-twelfth part of its volume? A line drawn from A to E and parallel to the line C D will represent the slope the river would then assume from the Gulf to New Orleans.

What would then result from the closure of these two outlets (Pass-a-lOutre and Southwest Pass), which the theory of the report most emphatically opposes?

The steep grade from the Gulf to the head of the passes would be lowered 1.56 feet, or about nineteen inches at the head of the passes, and the flood-line would be quite or nearly that much lower on the levees at New Orleans, and it would be ultimately lessened on every other levee between that city and the head of the Delta. The closure of all the outlets and passes below New Orleans, so as to confine the river in one channel to the sea, would alone materially lessen the necessary height of more than 2,000 miles of levees required on the two banks of the Mississippi, and would greatly benefit a large portion of the levees on its tributaries.

The same cause which would produce this result would effect an additional reduction of the flood-line, as each remaining outlet above New Orleans would be closed.

The reader must not infer that I would recommend the closure of Pass-a-l'Outre and Southwest Pass. This may be done advantageously at some distant day, but it should only follow a correction of the upper part of the river. I have referred to them here only for illustration.

OUTLETS RAISE THE FLOOD-LINE.

We will now see what would follow the opening of more outlets, which the report declares correct in theory, but reluctantly abandons for want of proper territory on which to apply it.

The Commission assume that a waste weir at Bonnet Carré crevasse, "discharging 250,000 cubic feet per second in great floods," would render the country below secure with the present levees. If this were so, three or four such waste weirs would lessen still more the flood-line below them. Suppose the river were thus depleted until the remaining water that would find its way to the sea by the present channel, would only equal the present volume of Southwest Pass. Nature has given to this pass a slope of $2\frac{2}{17}$ inches per mile to enable it to discharge its quota of the flood water of the river, and if the present great channel of the main river received only so much as is now discharged by the Southwest Pass, it would be impossible to maintain sufficient velocity of current in it, to prevent a deposition in its bed. This pass teaches us that a slope of $2\frac{2}{17}$ inches is requi-

site to prevent such depositions, and if the volume of the whole river be reduced to an equality with that of the Southwest Pass it would inevitably fill up and assume the slope of the Southwest Pass to the proposed waste weirs of Bonnet Carre. This, instead of protecting the lands below Bonnet Carre, would raise the flood-line at New Orleans (40 miles below Bonnet Carre) about five feet eight inches higher than ever, an effect precisely opposite to that assumed in the report.

The reader must not confound the effect that would be produced if the *entire* river in *one* channel went out at Bonnet Carre, with what would result if its discharge were broken up and dissevered by *many* outlets, as the Commission recommend. When the volume of the main stream is split up by islands its dissevered portions must necessarily assume steeper slopes to carry forward their burdens of sediment. Each outlet forms an additional island. If such islands were indefinitely multiplied it is evident that all the little channels forming them must fill up or assume steeper slopes.

CUT-OFFS WILL NOT FLOOD THE COUNTRY BELOW THEM.

I have said that precisely opposite effects will be produced from those anticipated by the Commission, if their plan and recommendation be followed. Let us see what their report says about cut-offs:

"Exact observations upon the Po, the Mississippi, and other rivers have established that the effect of a cut-off is to raise the water-level just below its site by an amount equal to half the fall in a straight portion of the river of equal length, and to depress its height just above by an equal amount, plus the head requisite to overcome the resistance due to the curvature of the bend. If it were possible to extend the system from the foot of the alluvial region to its head, the result would be to greatly raise the flood-level in the region below and to depress it in the region above the middle point. Hence, even if no other injury than this of submerging the lower half of the valley would result, the plan would be utterly inadmissible either in an engineering or a political point of view. But this is not all. The local increase of velocity and change of direction of currents resulting from a cut-off increase the caving in the bends both above and below its site. Indeed it is largely due to the frequent occurrence of these interruptions to the normal conditions of an unvarying river-bed, that the excessive caving in the upper part of the alluvial region is to be attributed. Five of them have occurred during the past quarter of a century, all with disastrous results to the river. So far from artificially aiding in their recurrence, it is therefore the emphatic opinion of this Commission that in every case they should be prevented, or at least retarded, if this can be done at any reasonable cost."

Suppose the river were shortened 40 miles by a cut-off, ending at Fort St. Philip, this, by the Commission's theory, would add the half of the fall in 40 miles to the flood-line at Fort St. Philip, which at 1.44 inches per mile would be 28.8 inches. Fort St. Philip is about

20 miles above the head of the passes, and this additional 28.8 inches would exactly double the present slope. That is, the *main* river would have to assume and maintain a flood slope of 2.8 inches per mile from Fort St. Philip to the head of the passes, or nearly the same slope which nature gives to the smallest of the three passes, if the views of the Commission be correct.

For such a great volume to maintain so steep a slope is simply impossible. There is no reason to apprehend any permanent elevation of the high-water mark below a cut-off, and there is no evidence of anything of the kind following the five cut-offs referred to by the Commission. The temporary rise which occurs immediately below, and immediately after *the sudden* opening of a cut-off, has been assumed by the Commission to be a permanent result.

The conclusions of the Commission respecting cut-offs are based in this instance also on the treatment of the river as though its bed were granite and its waters pure as snow.

Holland has had no overflows of the Rhine for more than sixty years, although the flood-line above Holland has been permanently lowered within that time as much as seven feet in some localities, by *cut-offs*, a system which the report declares to be "utterly inadmissible, either in an engineering or a political point of view," although practiced with signal success by engineers on a sedimentary river, remarkably like the Mississippi.

CAVING BANKS ONLY OCCUR FROM IRREGULARITIES IN THE RATE OF CURRENT.

By the "undercharged" theory of the Delta Survey Report, caving banks are attributed to the direct action of the current against them, by which strata of sand underlying those of clay, etc., are supposed to be washed out. This is not correct. If the water be charged with sediment to its *normal* supporting capacity, it can not take up more unless the rate of current be increased. Caving banks are caused wholly by the alternations in the velocity of the current. These alternations are inseparable from a curved channel, because the current in the bends is usually more rapid than on the points; but if the channel be nearly uniform in width, the caving caused by the curves will be very trifling. In proof of this, many abrupt bends exist in the lower part of the river, where the whole force of the current has set for years directly against them without any important caving of the bank. The bend of Fort St. Philip is a notable instance. Great differences in the width of the flood channel constitute the real cause of the destructive caving of the banks. These induce great irregularities in the slope of the flood-line, and consequently great changes in current velocity, by which the scouring and depositing action are alternately brought into very active operation.

The whole river below Red River proves this. Caving banks are much less frequent there than above, because the flood width of the river is far more uniform.

A correction of the *high water channel*, by reducing it to an approximate uniformity of width, would give uniformity to its slope and current, almost entirely prevent the caving of its banks, and through its present shoals, which now constitute the resting places for its snags, there would be a navigable depth, *in low water*, equal to that which now exists in its bends. By such correction, coupled with a few judiciously located cut-offs, the flood slope can be safely and permanently lowered above each cut-off, and in this way the entire alluvial basin from Vicksburg to Cairo can be lifted, as it were, above all overflow, and levees in that part of the river rendered useless. *There can be no question of this fact*, and it is well for those most deeply interested to ponder it carefully before rejecting it, for the increased value given to the territory thus reclaimed can scarcely be estimated.

I would, however, earnestly advise the immediate closure of the gaps now existing in the levees. It is not necessary, I think, to raise them to a greater height, in any locality, than twelve inches above the floods of 1858 and 1874. Where extensive lines of new ones are now required, they should be located to conform to a plan for the correction of the entire river channel, by which the present levees would be ultimately rendered useless, and the low-water channel of the river deepened to at least 20 feet from Cairo to New Orleans.

EIGHT ERRORS RECAPITULATED.

I believe I have conclusively shown that each of the following eight statements is in conflict with natural laws or observed facts, and is therefore erroneous:

1st. That increased volume will permanently raise the flood-line.

2d. That outlets will permanently lower the flood-line.

3d. That cut-offs will permanently raise the flood-line below them.

4th. That the river water is always undercharged with sediment.

5th. That no relation exists between current velocity and quantity of sediment suspended.

6th. That crevasses do not cause deposits below them.

7th. That the bed of the river cannot yield.

8th. That a clay, which resists the action of the strong current almost like marble, forms the real bed of the river.

These mistaken opinions form the basis of the plan and recommendations of the Levee Commission. As the improvement I am conducting at the mouth of the Mississippi is based upon views precisely opposite to them, it is not surprising that the Chief of Engin-

eers, U. S. A., believes the jetties at the South Pass will be unsuccessful; but after this exposition, it will not be necessary to reply to his recent arguments on that subject.

JAS. B. EADS.

St. Louis, February 19, 1876.

REVIEW

OF HUMPHREYS AND ABBOT'S REPORT ON THE PHYSICS AND HYDRAULICS OF THE MISSISSIPPI RIVER.

[Reprinted from Van Nostrand's Engineering Magazine.]

As the report on the Mississippi river made by Generals Humphreys and Abbot, in 1861, has been recently republished by the Government, and as it contains certain grave errors touching the navigation of the river and the reclamation of its alluvial basin, I desire to expose them, and to show that many of the statements made by the authors of the report are not sustained by the facts to which they refer. If the reader will follow me attentively, I promise to demonstrate, to his entire satisfaction, the utter absurdity of these statements.*

It does not interest the general public to know whether the quantity of sediment carried by the water of the river is adjusted by the rate of its current or not, or whether the real bed, on which rest its moving sand bars, is of recent, or of ancient geologic stratification, or whether it wears rapidly or slowly under the action of its current, unless these questions are known to have an important bearing upon the commer-

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* In 1874 I proved to the satisfaction of the Congress of the United States, *by the data contained in this report*, that the theory of bar formation at the mouth of the Mississippi advanced by its authors was totally wrong, and thus secured for the river an unobstructed and open outlet to the sea through the bar at South Pass. It is needless to say that the predictions made by General Humphreys regarding the re-formation of the bar in advance of the jetties have not been realized. This paper is intended to expose other erroneous theories advanced in the same report, which stand in the way of a correct system of improvement of the entire river, and which are declared to be conclusively demonstrated by a patient scientific and experimental investigation.

cial and agricultural prosperity of the Valley of the Mississippi. When this is known to be the fact, the scientific interest in them is completely dwarfed by the overwhelming practical bearing which they have upon great national interests. It is for this reason that I select your widely circulated journal as the surest means of thoroughly reaching the intelligent readers of the country, rather than to attempt, through the less extensively circulated records of any of the scientific bodies of which I am a member, an exposition of the dangerous errors advanced by Humphreys and Abbot.

THE RELATION BETWEEN THE CURRENT AND THE SUSPENDED SEDIMENT.

In 1874, I stated in a pamphlet, that the chief portion of the sediment discharged by the river into the Gulf is carried in suspension, and "that the amount of this matter, and the size and weight of the particles which the stream is enabled to hold up and carry forward, depend wholly upon the rapidity of the stream, modified, however, by its depth."

General Humphreys immediately afterwards said,* this statement is "in direct conflict with the results of long continued measurements made upon the quantity of earthy matter held in suspension by the Mississippi river at Carrollton (near New Orleans), and at Columbus (twenty miles below the mouth of the Ohio), one of the chief objects of which was to determine this very question, whether any relation existed between the velocity and quantity of earthy matter held in suspension. These results prove that the greatest velocity does not correspond to the greatest quantity of earthy matter held in suspension; on the contrary, at the time of the greatest velocity of current at Carrollton, the river held in suspension but little more sediment per cubic foot than when the velocity was least." †

These results, when correctly interpreted, prove precisely the contrary of the idea here conveyed by General Humphreys. He says that my statement is in direct conflict with them, and then proceeds in effect to tell us that there is no relation between the velocity of the current and the sediment carried in *a cubic foot of water*, which is a very different thing, as the reader will soon see.

General Humphreys evidently means to convey the idea that the most rapid current carries but little more sediment than the least, when in fact, by his own tables, it carried more than twenty times as

* See Executive Document 220, Forty-Third Congress. Also last edition of Report on the Mississippi River, page 674.

† See last edition Mississippi River Report, page 188, and Appendix D.

much as the least current at Carrollton, and more than forty times as much at Columbus.

They use the terms "a cubic foot of water," and "the current," as expressions having one and the same meaning; whereas the current per second represents the force due not to *one* only, but to an immense number of cubic feet of water passing, in each second of time, by the place where the current is measured; and it is the total sediment suspended in this immense number of cubic feet that should be compared with the rate of the current per second.

One of the chief objects, we are told, was to determine "whether any relation existed between the velocity and the quantity of earthy matter held in suspension." In what? *In a cubic foot* of water, or in the whole river? Certainly in the latter, for the quantity in a cubic foot is of no practical value, except as a means to determine its relation to the whole quantity.

They pushed their investigations, however, only to the extent of trying to find the relation between the current per second and the sediment in a cubic foot. Failing to discover this, for they proceeded no farther, and supposing that they had solved a problem in which they had neglected two essential elements, they announced their astonishing discovery that no relation whatever exists between the rate of current and the quantity of sediment suspended by it; or, in plainer English, between *cause* and *effect*.

This question could only be solved by bringing the elements of *space* and *time* into the computation for the sediment, just as they are brought into the current measurement, that is by comparing the mean velocity *per second* with the total weight of sediment suspended per second. They, however, compared the mean velocity in every instance with the mean sediment contained in but a single unit of the river's volume, and they not only published the results of this meaningless comparison, as *a proof* that there is no relation between the rate of current and the quantity of sediment, but they have founded unsound theories upon this error, and have officially advised a dangerous system of river treatment based upon it.

I will now show *why* they should have compared the current, per second, with the total quantity of sediment passing by their point of observation in the same unit of time. To make this easily understood by the general public, compels me to state much that will be commonplace to the scientific reader.

Motion cannot occur in matter without an expenditure of force. The transportation of sedimentary matter in water, can, therefore, only result from an expenditnre of force, and only by supplying the requisite amount of force, as it becomes exhausted, can these matters be lifted up and kept from falling back to the river bottom. Being heavier than water, it is just as impossible to uphold them in it without force, as it is to raise chaff in the air, or sand and dust in a whirl-

wind without it. The current caused by the river flowing from a higher to a lower level supplies this force.

The investigation of all questions relating to the expenditure of force belongs to that branch of science called *Dynamics*, and in all such problems, whether they relate to a tread-mill or a steam engine, to the tiniest ripple or the grandest river, to a grain of sand as it moves onward to the sea, or to the most majestic planet that pursues its pathway in the heavens, each and all involve the consideration of four distinct elements in their solution; and unless each one of these be duly considered, no assumed solution of the question can be worth the paper on which it is made, except perhaps to "point a moral."

These elements are, first, *force*, second, *matter*, third, *space*, and fourth, *time*. Gravity and pressure are examples of the first element, and one of these, gravity, constitutes the first factor in our problem. The term, volume, or mass, is used to indicate the quantity of the second element, while the term speed, or velocity, embraces the last two elements, and indicates the space through which the force acts and the time involved in the action.

The amount of force expended can only be ascertained by knowing the weight or pressure exerted, the space through which it acts, and the time occupied in such action.

The relation of these four elements to each other may be illustrated by suspending two equal weights from the ends of a lever with equal arms, supported at its middle. While at rest they present simply a statical problem, in which force, matter and space alone are involved. When in motion, however, the other element, time, necessarily enters into the problem. If motion be imparted to the weights, and one sinks towards the earth, the other will be raised through a space exactly equal to that through which the other falls, and in the same time in which the other falls. The velocity and mass of the descending weight gives the measure of the force expended. This force can only be determined by these three elements: first, the weight; second, the space through which it moves; and, third, the time required to move through the space. *The work done* consists in its raising the other *weight* through the same *space*, and in the same *time*. Therefore the force expended will be precisely the same that is required to raise the same weight, through the same space, in the same time. Hence it is an axiom that "The work done must bear an invariable quantitative relation to the amount of force expended."*

If the point of support of the lever be moved from the center toward one weight until the latter will balance one only half as heavy, it will then be found that when the large weight descends in one unit of time through a certain space, the small weight will have

* Mayer.

been raised through twice that space in the same unit of time, and therefore, the small one will have moved with twice the velocity. Hence, if we raise a weight through twice the space, in the same time, we must either double the force, or lift but one-half the weight. If we reverse the motion of the weights, and the smaller one descends, we illustrate the fact that by doubling the velocity, half the force will lift twice the weight.

In the steam engine the pressure of the steam takes the place of the pressure or force exerted by gravity. To determine the power of the engine we must have, first, the pressure upon the piston; second, the space through which it moves, and third, the time occupied in its movement. If the same pressure be maintained per square inch in each of two cylinders, and the velocity of the piston in one be twice as great as in the other, the more rapid one will develop as much power as the other with half the area of piston; just as half the weight on the doubled length of the lever arm can develop the same amount of force as the whole weight, because it will then move with twice the velocity.

The power of a waterfall is estimated by the same three elements. The weight of the water falling in one minute of time and the number of feet of space through which it falls in the time, are multiplied together, and when divided by 33,000 foot pounds, the quotient will represent the horse power of the waterfall or head of water; a horse being supposed to be able to raise 33,000 pounds, one foot high, in a minute of time.

It is unnecessary to point out by farther illustration the fact that these three elements, matter, space and time, are inseparably related in any investigation to determine either the amount of force expended or of work done. I need only add that no matter how intricate the machinery, or secret the medium through which moving bodies transmit their forces, these three elements are as absolutely requisite to determine the amount of the force expended, or the work done, as the depth, width, and length of a rectangular box are, to determine its capacity; and no matter how occult may be the relation between them, it is nevertheless as indissoluble, complete and perfect as this simple illustration.

The work performed is precisely equal to the force expended when operating any steam, water or other motor, but the work *practically* considered is of two kinds: one of which may be called profitable or visible work, and the other unprofitable or invisible work, the latter being that part of the force which is expended in overcoming friction, back pressure, atmospheric resistance, radiation, etc.

The work done by the force which the Mississippi River expends we may, for the sake of illustration, also divide into two kinds, and call the first, invisible, or unprofitable work, among which we may class the overcoming of the friction of the bed of the stream, the

friction among the particles of water, the resistance due to the irregularities and bends in the channel, the atmosphere, etc., leaving to be considered, as the visible or profitable work, the transportation of its immense burden of sediment. The problem we are considering and which these gentlemen claimed to have determined, is the relation which the current, or force, expended by the river bears to this great burden of earthy matter.

Let us suppose a railway train be used in transporting grain, and that we wish to determine the relation between the force (or coal) expended, and the quantity of grain carried; we would carefully ascertain the total coal burned in some definite *time*, for instance, in one hour, and also the *total weight* of the grain carried in that hour, and likewise the *space* over which it was carried during that hour. We would then be able, by comparing the total coal with the total weight, to declare absolutely that so much coal or force expended, was equal to the carrying of so much grain a certain distance in one hour, and the relation between the force expended and the work done would be so expressed.

In such investigation we would have 1st, force (the coal); 2d, matter (the load of grain); 3d, space (the distance the load is carried); and 4th, time (the hour during which it was carried). By repeating the measurements under similar conditions, but with different quantities of time, space and weight, this relation between force and work would appear constant and inseparable. An instructive comparison could only be made, either between the *totals* of the force and work, or between their respective *units*, and in either case *time* and *space* would be indispensable elements to be considered. But if the total coal be only compared with the weight of a *single bushel* of the grain, and no note be taken of the *space* through which it was carried, nor of the total number of other bushels that were carried in the same *time*, the comparison would have no significance whatever. A diagram to represent such a comparison, as an ultimate solution of the question, would not only be meaningless but absurd; yet it would be precisely similar in principle to the diagrams which Humphreys and Abbot represent on plates XII. and XIII. of their report, where the current per second is contrasted with the sediment found in a single cubic foot of water. An accurate *fac simile* of plate XIII. is herewith shown. (See diagram No. 1.)

If the mean current at Columbus was six feet per second, an entire section of the river six feet long must have moved at that place and time through the space of six feet, and the force expended was, therefore, the entire force due to the motion of this whole section during that second.

The mean current given in feet per second, is, therefore, an exponent of this whole force, and if it be six feet per second, it can only be intelligently compared with the total sediment carried in an en-

tire section of the river six feet long, and not with that in a single cubic foot. If we multiply the cross section of the river in square feet by the current in lineal feet per second, the product would be the number of cubic feet in the section, and these multiplied by the number of grains of sediment in one foot, would give the proper amount for comparison with the current.

As the work done and the force expended must be precisely equal, it is evident that the three elements, namely, *matter*, *space* and *time*, are as necessary to determine the amount of *work done*, as they are to determine the amount of force expended.

In appendix D of their report will be found tables, giving in cubic feet the daily volume of water flowing per second by the velocity base, or point where these measurements were made. These quantities were ascertained by multiplying the cross section of the stream in square feet, each day, with the mean velocity of the current at the time in linear feet per second. The two absent dynamic elements, namely, *time* (one second), and *space* (the linear feet the river moved in one second), are thus included in these tables. By taking the average or mean weekly discharge in these tables, and multiplying it with the mean sediment in grains found each week in one cubic foot of water, given in the tables, we get the proper quantities of sediment to compare with the average rate of current per second.

Diagram No. 2 is prepared in this manner from precisely the same data which Humphreys and Abbot used to prepare Diagram No. 1, except that in mine the absent elements, *space* and *time*, have been included as above explained. A third line is shown on my diagram which gives the mean weekly volume of discharge, by which the total weekly mean of sediment was ascertained.

If the relation between the current velocity and the quantity of sediment does not exist, as Humphreys and Abbot assure us, no correspondence or synchronism could be graphically shown between them on diagram No. 2 by any possibile scientific analysis to which these data can be subjected. By their diagrams, none whatever is shown, because of their error.

An inspection of diagram No. 2 proves the existence of this relation in a way that admits of no dispute, and shows how remarkably sensitive the sediment is to any change of velocity in the current. This is particularly noticeable at each period when the current began to decline. The river rose and fell six times at Columbus while the observations were being made. These periods are indicated by the letters A, C, E, F, G, and H. The loss in velocity at each of these six periods, during the eight months, is invariably and *immediately* marked by a corresponding reduction in the quantity of sediment. No one can look at these two diagrams, made from the same tables and to determine the same question, without feeling assured that

"Some one has blundered."

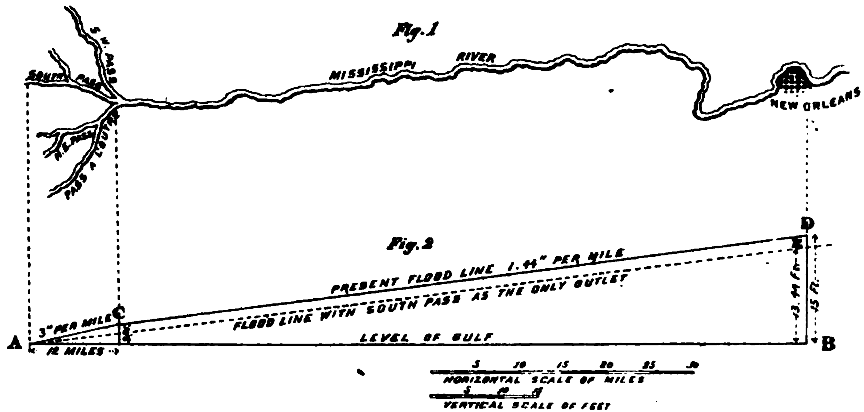
Fig. 1
S. W. PASS
SOUTH PASS
N.E. PASS
PASS A L'OUTRE
MISSISSIPPI
RIVER
NEW ORLEANS
Fig. 2
D
E
C
A
B
3" PER MILE
PRESENT FLOOD LINE 1.44" PER MILE
FLOOD LINE WITH SOUTH PASS AS THE ONLY OUTLET
LEVEL OF GULF
12 MILES
13.44 Ft.
15 Ft.
5 10 15 20 25 30
HORIZONTAL SCALE OF MILES
VERTICAL SCALE OF FEET

A diagram made in the same manner from the Carrollton observations will show an equally striking evidence of the intimate relation between the rate of current and the quantity of sediment, which has been so persistently and dogmatically disputed.

The error made by Humphreys and Abbot when investigating the results of their experiments at Columbus and Carrollton, consists in supposing they were comparing a definite exponent of the *force* with a corresponding exponent of the *work*, when, in fact, the elements of *space and time* were wholly absent in the exponent of the work; and not only were these neglected, *but only one single unit of the third element of the work* was taken as the corresponding exponent to compare with the force.

Suppose we should attempt to show the relation between a certain quantity of grain and the capacity of a rectangular box which it had exactly filled. Having ascertained the number of cubic inches of the grain, what relation could we hope to show between this quantity and the capacity of the box, if we compared it with only one single inch of the length of its bottom? Not only would we be ignoring the total length of the box, but we would also be neglecting the two other factors of the problem, namely, its width and its depth, and the comparison, therefore, would be utterly unintelligible. Such a mistake would be inexcusable in one who had barely entered on the threshold of geometry. The mistake made by Humphreys and Abbot is similar to this, and it is one equally unpardonable even in the merest tyro in the science of dynamics. Yet, relying solely upon this method of investigation, the Chief of Engineers of the United States army, to defeat the adoption of the present system of improvement at the mouth of the Mississippi River, actually prepared a letter which was read in the House of Representatives in 1874, and which referred to the subject we are discussing in the following language: "It is probably unnecessary for me to say here that the statements which Mr. Eads has made in the pamphlets he has published concerning the conditions existing in the Mississippi River and at its mouth are the mere revival of old assumptions, which experimental investigation has long since shown to be utterly unfounded in fact."

Having clearly explained how their defective knowledge of the principles of dynamics led them astray, and having proved by their own testimony that they are clearly in error, let us now see to what absurd conclusions their unfortunate mistake carried them.

Referring to their experiments at Columbus and Carrollton, they say on page 135: "An inspection of the preceding table must convince any one that the Mississippi water is undercharged with sediment, even in the low-water stage. A most important practical deduction may be drawn from this fact, namely, the error of the popular idea that a slight artificial retardation of the current—that

caused by a crevasse, for instance, must produce a deposit in the channel of the river below it."

On page 417 this undercharged theory is repeated, as follows:

"A glance at the two diagrams is sufficient to demonstrate the falsity of the assumption that Mississippi water is always charged with sediment to the maximum capacity allowed by its velocity."

Having exploded the "error of the popular idea" that cause and effect are related, we need not be surprised at this *undercharged theory*. And although we may have supposed that matter can not move independently of law, and that neither an atom nor an avalanche can stir except in strict obedience to ordinances more fixed than those which swayed the Medes and Persians, we must be prepared to believe that the sediment of the Mississippi is an exception to this rule, for, having proved conclusively that its water is always undercharged, we are gravely assured on page 135, "If the water be undercharged, the distribution of sediment will follow no law, the amount at any point being fixed by the accidental circumstances of whirls, boils, etc." With such astonishing declarations as these, the reader will be partially prepared for the no less wonderful announcement that as the sediment will follow no law, the feeblest current can carry just as much of it as the most rapid current.

This statement will be found on page 684 of the last edition. It is as follows:

"In fine, these measurements upon the quantity of earthy matter suspended in the Mississippi River show that at no time has the water been so heavily charged with it that the current could not carry it along in suspension to the same extent as it did when the quantity of earthy matter was least; and they further show that *the current* of the Mississippi River, when most feeble, can carry in suspension the greatest quantity of suspended earthy matter found in it, to the same extent that it can carry the least quantity found in it."

I know of but one other statement concerning the wonders of this river that can compare with this one. In the last eighty years several cut-offs have occurred below the mouth of the Ohio, by which the channel was shortened about seventy miles. Based upon this fact, a distinguished writer has published the startling prediction that within a few centuries two cities on the river (Cairo and New Orleans), although now distant from each other one thousand miles, must, by this shortening process, be inevitably drawn together! By an inverse method of reasoning on these facts, he arrives at the interesting conclusion, that in some remote geologic period the Mississippi extended to Cuba! *

When, pursuing a different line of investigation, distinguished en-

* Mark Twain.

gineers arrive at the equally astonishing conclusion that the current of the Mississippi when most feeble can carry as much sediment as it can when most rapid, we may, from the standpoint of common sense, safely assume that while the deductions, in each case, rest upon facts, the conclusions in both were arrived at by defective methods of scientific investigation.

If we examine these Carrollton and Columbus experiments, we do not find this surprising statement about the power of feeble currents verified.

In the quotation, I have italicized the words "the current," to attract attention to the fact that no distinction is made between what *the current* carried and what *a cubic foot* of water carried. Diagram No. 2 shows what the current carried, while diagram No. 1 shows what was carried in *a cubic foot*. The one emphatically disproves this absurd statement, while the other furnishes no ground whatever for making it, because it conveys no idea at all of the relation between the current and the sediment.

At Columbus, the most feeble current carried but ten million grains of sediment per second, while during the third week in April, when the current was about four times as rapid, it carried 480 million grains, *or forty-eight times as much* as "when the current was most feeble." At Carrollton the current was most feeble in November, being but little more than a foot and a half per second, and then it carried less than 22 million grains, while in June, when the current was nearly three times as rapid, it carried 500 million grains, *or nearly twenty-three times as much* as when it was most feeble!

Dr. G. Hagen, Director General of Public Works in Prussia, and one of the most eminent engineers in Europe, in a recent criticism upon Humphreys and Abbot's theory regarding the distribution of velocity in flowing water, says:

"The young student of hydraulics is sometimes compelled to accept certain theorems as true and proven which, to say the least, are still doubtful; but he has as yet never been expected to receive devoutly a demonstration like this, and to regard it as a progress of science." This comment seems peculiarly applicable, likewise, to their conclusions regarding "the relation between the current and the suspended sediment."

On the same page of their report from which the preceding remarkable extract is taken is the following:

> "This proposition, therefore, respecting certain velocities of current always carrying certain fixed quantities of earthy matter, and always adjusting those quantities according to its own variations of strength, is so entirely disapproved by facts that it will not be considered again."

In view of the fact that their own tables prove the utter fallacy of

this statement, it is amusing to see the satisfaction with which it seems to be uttered.

It will be observed that all of these mistaken conclusions rest upon the assumption that the sediment found in *a cubic foot* of water, moving at different velocities, was a correct exponent of the ratio between the speed of the river and the burden it carried.

After referring to plates XII. and XIII. to prove that "the river is never charged to its maximum capacity of suspension," they declare (page 417): "Hence if enough water had been taken from the river at the date of those floods (1851 and 1858) to reduce its velocity nearly to that of the lowest stage, no deposit in its channel could have occurred."

The highest velocity at Carrollton was 6.16 feet per second, and the sediment was then only 252 grains per cubic foot. In September the current had declined to 2.44 per second, while the sediment was 268 grains per cubic foot. These quantities were doubtless in view when the above declaration was made, because, as far as their "experimental investigation" had advanced it showed that a current less than 2½ feet per second actually carried more sediment *per cubic foot* than a current of over 6 feet per second. But the high current carried 280 million grains per second, because 1,140,000 cubic feet of water were then passing per second, while the low current carried but 100 million grains per second, or but little more than one-third as much; because the volume of water was then only 375,000 cubic feet per second.

At Columbus, 320 grains per cubic foot were carried with the highest current, 8¼ feet per second, in June, while 608 grains were carried in August with a current of 2.57 feet per second.

But when we bring in the absent dynamic elements of *space* and *time*, and ascertain by them the total quantity of work really done by the current at Columbus, we find that the river carried 444 million grains per second with the high current, and only 180 millions with the low current, because its volume of discharge with the high current was nearly 1,400,000 cubic feet per second, and only 280,000 with the low current. Hence, it is simply impossible that the high water burden can be carried with the low rate of velocity without deposition occurring.

We learn from the illustration of the lever and weights, that the same force can only raise half the weight if it raise it to double the height in the same time. Hence, we should not expect to find as much sediment *per cubic foot* in deep water, with a given velocity, as in shoal water. This fact will account for the quntity being greater per cubic foot in some of the measurements when the current was moderate, than when it was most rapid. The greater distance between the sediment and velocity lines during the first four months on diagram No. 2 is very marked. These were the high water months,

and the modifying effect of the depth of the stream on its power to suspend the sediment is clearly shown by the greater distance between these lines.

The depths as well as the velocities are usually greatest during floods. When the current was 8.25 feet per second, the depth at Columbus was 27 feet greater than when it was 2.57 feet per second, yet the tables show that the low current supported a greater quantity *per cubic foot* than the higher velocity, because, *first*, it did not raise it so high above the bottom; and, *second*, because the river was falling. As many hours are necessary, even in still water, for all the sediment to fall, it must be evident that when the river is falling and the current diminishing, the water will have a greater amount in suspension than is then due to the velocity; and that when it is rising and the current increasing, it will then have less in suspension than the velocity would indicate. Therefore, the quantity found at a low velocity, if the river be falling rapidly, may be much greater *per cubic foot* of water, not only because of less depth, but also because of a diminishing velocity. The diagram (No. 2) shows that both causes operated to induce this great charge of 608 grains per cubic foot with this low rate of current.

The tables of sediment show also that the lower part of the water is somewhat more largely charged with sediment than the upper. This would act as an additional cause for the low water currents showing a larger ratio of sediment, particularly when the river has been falling some time. When it first begins to lose its high velocity, the largest particles, such as gravel (which is undoubtedly carried in *suspension* with the higher velocities, in moderate depths), and coarse sand are first deposited. These fall rapidly, while the smaller particles require more time for settlement, according to their magnitudes and specific gravities. Fine particles of sand, which require the microscope to make them visible, remain a long time suspended, and are carried with very low velocities. The material which forms blue and other clays is deposited during periods of low water and sluggish currents, and microscopic sand is always present in these alluvions. Many strata of hard blue clay were encountered by the piers of the St. Louis bridge, when sinking them through the 80 feet of deposit overlying the limestone bed of the river. None of these were more than six or eight inches thick, and each was, no doubt, deposited during a single period of low water. They were alternated with layers of sand and gravel.

Caving banks generally occur when the river is falling, because then the support or pressure of the river having been withdrawn from them, such as have been undermined by the rapid high water currents topple over into the stream, and thus add temporarily to the normal charge of sediment then carried in suspension. It is quite possible that the high charge of 608 grains per cubic foot, with a ve-

locity of only 2.57 feet per second, was partly due to caving banks a few miles above.

Diagram No. 2 shows that in the eight months during which the sediment observations were made at Columbus, there were six periods when the river fell from levels previously attained, and at *each period* the quantity of suspended matter diminished *at once* with the loss of current. This instantaneous evidence of the intimate relation between the velocity and the quantity carried, so clearly shown by the *weekly* mean of these quantities on the diagram, would be less apparent in curves representing each experiment. Slight errors in weight, or in current measurements and local causes, such as the caving in of the banks above the observer, might make the sympathetic action between the current and sediment appear less harmonious if the mean of a number of experiments were not taken. The weekly mean taken by the authors of the report, thus tends to bring out in bolder light the force of their own testimony against them.

In addition to errors in measurement and caving banks, other causes, such as the differently charged waters of tributaries moving with altered velocities in the parent stream, and the difference in the time required for different kinds of sediment to deposit, may each operate to modify the results of such experiments as those we are discussing, and hence absolute synchronism in the curves of velocity and sediment cannot be expected. This agreement is, however, so marked in diagram No. 2, as to bear excellent testimony to the care with which Messrs. Webster and Fillebrown conducted the experiments at Columbus.

THE BED OF THE RIVER.

The wonderful discoveries made by Humphreys and Abbot, through their unique method of investigating dynamical phenomena are supplemented with others in geology scarcely less surprising. On page 14 of their report we find the following:

"For instance, the Mississippi had always been regarded as flowing through a channel excavated in the alluvial soil, formed by the deposition of its own sedimentary matter. So important an assumption was inadmissible; and great pains were accordingly taken to collect specimens of the bed wherever soundings were made, and by every means to ascertain the depth of the alluvial soil from Cape Girardeau to the Gulf. This investigation has resulted in proving that the bed of the Mississippi is not formed in alluvial soil, but in a stiff, tenacious clay of an older geological formation than the alluvion."

The following occurs on page 91:

"What then constitutes the real bed of the river, upon which rest the moving sand-bars, and the new willow-batture formations? From the mouth of the Ohio down, at least as far as Ft. St. Philip [forty

miles above the Gulf] it seems to be composed of a single substance, a hard, blue or drab-colored clay."

The age of the bed of the river is a matter of little practical interest to the public, and I do not therefore propose to discuss it. But whether it is composed of a clay that yields slowly to the strongest currents, and resists their action "almost like marble," is a question of the utmost importance to the people of the whole country. The intelligent reader need only be told that within three years, the Congress of the United States has been advised to incur an outlay of forty-six million dollars, based on the proposition that the bed of the Mississippi will not yield to the action of its strong current, to have his curiosity aroused upon this important question.

The existance of this substratum is asserted by Humphreys and Abbot in the most confident manner, *as a fact conclusively established by the numerous soundings of the Survey with prepared leads.* We are told on page 90, in reference to these soundings, that "The details of these operations are explained in Chapter IV., and the results exhibited in Appendix C."

Turning to chapter IV., to learn by what devices this clay had been discovered "beneath the moving sand-bars and the new willow-batture formations," we find them to consist of nothing more than "a sounding chain and plummet." The latter is thus described: "The sinker, varying from ten to twenty lbs. in weight, according to the force of the current, was a leaden bar whose bottom was hollowed out and armed with grease, in order to bring up specimens of the bed of the river; the patent lead was also used for the latter purpose."

Now, when it is remembered that *no borings were made either on the banks or in the bed of the river to test the existence of this unyielding clay,* the reader will appreciate how astonishingly the results of these soundings have been magnified, if he will examine them in Appendix C, and compare *the facts* there recorded with the extravagant reference made to them in the report.*

On page 90, under the heading of "*Geology of the Channel,*" we are told that "A knowledge of the character of the bed of the Mississippi River is of the highest practical importance, as will be hereafter seen, and great efforts have been made to acquire it."

The above extract, and the statement on page 14, that "great pains were accordingly taken to collect specimens of the bed wherever

* The record of the artesian well at New Orleans is given in the report, and reference is made to it on page 465 to prove that the river deposits overlying this ancient and imaginary clay, extends only 40 feet below the level of the gulf at New Orleans, (or 55 feet below high water mark,) as a sound cedar log was struck 158 feet deep by the auger, and is reported in the record, and therefore lies 98 feet deep in this marble like clay. It is to be regretted that an explanation of how it got there, was not given in the report.

soundings were made," caused me to look forward to an examination of the results of these "great efforts," as a matter of considerable labor, more especially as they had been spoken of on page 412, as "an extended series of measurements." I carefully examined the first eleven tables of soundings in Appendix C, and found that they did really constitute "an extended series of measurements;" for they comprise the only recorded lines of soundings made by Humphreys and Abbot on the Mississippi River between Cape Girardeau and Vicksburg; a distance of 650 miles! The remaining tables are the record of soundings made at Vicksburg and below that point down to Fort St. Philip, a distance of 500 miles more.

As five of the eleven lines were run across the river at Columbus, and two at Lake Providence, the other four had necessarily to be considerably *extended* to make "this investigation" into the geology of 650 miles of river a very thorough one.

About fifty soundings, more or less, were made on each one of the eleven lines, but the grease was evidently bad, or the patent lead was a failure, for, on the first line of these numerous soundings, only *one* solitary sample was obtained. The grease seems to have given out altogether on four of the lines. When the two were run across at Lake Providence this must have been the case, or it was a bad day for geological research, because no specimen whatever was obtained in either of these two lines, and thus a space nearly two hundred miles long, between Napoleon and Vicksburgh, was not sampled at all. The prepared leads appear to have worked badly on the third line also, as only two samples were obtained there. In the entire eleven lines of soundings, that were made across the river in this 650 miles, there were only *thirty-five samples* of the bottom secured!

The different kinds of material were carefully noted in a separate column under the head of "Remarks."

When we reflect that each of these precious specimens was deemed to be a key to an unwritten record running away back into the dim past, where azoic and palaæozoic cycles inclose the sublime genesis of the Father of Waters, we cannot fail to note the terse expressions with which, in such simple terms as "*Gravel, Clay, Sand,* or *Mud,*" these antediluvian treasures are recorded. This brevity is, however, fully compensated for in Chapter II., where "the results exhibited in Appendix C are discussed."

Let us now examine the conclusive evidence given of the existence of this unyielding substratum by "the samples of the bottom which were carefully preserved for examination and comparison."

The thirty-five samples secured in this 650 miles of river, when shorn of the imposing verbiage with which they are referred to in the report, certainly constitute a very small basis on which to rest the positive statement that the bed of the Mississippi is composed of an unyielding clay, even if we suppose each one of the samples was a

specimen of *clay;* but this small basis becomes supremely ridiculous when the fact is stated, that twenty-five of these samples actually consisted of pure sand, and that only *seven* of the whole thirty-five were of clay alone! And then again, each one of the seven areas thus sampled by the prepared leads was probably not larger than the palm of a man's hand!

Moses, when stopped on Mount Pisgah, might as well have tried to analyze the subsoil of the promised land by gazing at it, afar off, as for these gentlemen to tell anything about a mythical substratum of clay under the shifting deposits of the river by means of their greased leads. The present age demands *proof*, not guesswork and assertion, and it is utterly impossible that anything adhering to the bottom of a tallowed plummet from the bed of the Mississippi, can furnish any evidence whatever as to the kind of material that lies one inch below where the sample was thus secured.

It is scarcely necessary to refer to the soundings below Vicksburg, after this statement, except to say that eighty-two lines were run in that part of the river, and that 56 of these were made in 45 miles of the river near New Orleans. In 116 miles of the river between Vicksburg and Natchez, only two samples were obtained. Of the total 93 lines run, no samples were obtained in 35 of them, and of all the samples taken, only about one in four were of clay alone, while more than one-half of the whole number were of pure sand. It is needless to say that all of the samples were just such materials as the river is constantly transporting in suspension, and that they do not furnish a particle of evidence that the bed is formed of any other substance than is own deposits.

Blue clay is one of the deposits or alluvions of the river, and is found everywhere in the alluvial basin, in layers alternating with the sand, gravel and earthy deposits, which compose its bed and banks. It is found deposited in old sunken wrecks,* on sunken rafts, and on the "rack heaps," or accumulations of drift-wood which lodge against snags or islands. It was doubtless an old steamboat wreck, or a rack heap which caused the loss of the sounding leads, referred to in Chapter II., and which marked the chain with this blue clay thirty feet above its broken end. Yet the clay, found on the chain and the uneven depths where it was broken, led the authors of the report to suppose that the river bottom was "full of blue clay ridges and lumps many feet high."

One proof of the fact that the bed of the river *does* yield readily to the action of the current will be seen in the great number of curved

* Col. Andrews states that a barge which lay submerged during only two seasons of low water at the jetties had a stratum of blue clay nearly a foot thick deposited in it, which was so tough and sticky that the men could scarcely dig it out, because it adhered to the shovels so tenaciously.

lakes lying on each side of its present bed, and extending from the upper to the lower end of the alluvial district. Each one of these was once a part of the river channel. The following correct explanation of their formation is copied from page 96 of the report:

"It occasionally happens that by this constant caving, two bends approach each other, until the river cuts the narrow neck of land between them and forms a 'cut-off,' which suddenly and materially reduces its length. The increased slope of the water surface at once makes this new bed the main channel of the river. The upper and lower mouths of the 'old river' are gradually silted up with sediment, drift-wood, etc., until eventually one of the crescent-shaped lakes so common in the alluvial region is formed."

The rapidity with which the current sometimes cuts away the tough blue clay, so frequently met with in its bed and banks, may be inferred from the following account of the formation of a cut-off given by Major Suter, U. S. Engineers, in his report:

"Davis', one of the most recent of these cut-offs, and also the largest, occurred in 1867. It cut off Palmyra Bend, eighteen miles below Vicksburg, a bend which was eighteen miles long while the distance across the neck was only 1200 feet. The exact slope of the river at the time is not known, but it was probably not far from 0.3 foot to the mile; therefore the difference of level on the two sides of the neck was about 5½ feet. When the river broke through, the whole of the fall had to be absorbed in the 1200 feet of distance, making a rate of about twenty-four feet to the mile; and it can readily be imagined that the whole immense flood volume of the Mississippi, flowing with the enormous velocity due to this great slope, produced very marked effects. The roaring of the waters could be heard for miles; and in the course of a few hours, a channel a mile wide, certainly over a hundred and probably nearly two hundred feet in depth, had been excavated.

It is impossible to reconcile the excavation in a few hours of "a channel a mile wide and certainly over a hundred and probably two hundred feet deep," with the existence of a clay that "resists the action of the strong current, almost like marble." Such a clay is undoubtedly a myth.

THE PRACTICAL IMPORTANCE OF THESE TWO QUESTIONS.

Let us now look at the immense practical importance of these two facts which are so stoutly and degmatically denied by Humphreys and Abbot. If the quantity of suspended sediment *is* regulated by the current, and if the bed of the river *is* formed of its own sedimentary deposits, instead of this unyielding and marble like clay, then it is entirely practicable to lower its flood line or slope, and deepen its channel by simply constructing light willow or brush

dams during low water on the shoals which are then dry, or nearly so, at the various wide places in the river where the bars always exist. These dams would cause the deposit of more sediment on the shoals, by checking the current, and would deepen the contracted channels that would remain by increasing the current in them. In this way (without undertaking to straighten the river, which would be supremely foolish and impracticable), the high water channel would be brought to a comparative uniformity of width, by gradually encouraging, from year to year, the deposition of sediment over the wide expanses, and this uniformity of width would produce a uniformity of depth, which in turn would insure a uniformity of current, and this would practically stop the caving of the banks. A uniformity in the width of the high water channel would do more however than all this, for it would lower the flood line and practically dispense with the use of levees in protecting against overflow, an area equal to the State of Indiana.

If Humphreys and Abbot's theories are sound, such an improvement of the river channel, and such abandonment of the levee system, is totally impracticable.

The following quotations show that these dangerous theories have been adopted by the United States Levee Commission, which recently recommended a system of levees below the mouth of the Ohio at an estimated cost of nearly $46,000,000. It says in its report,* page 8, [Ex. Doc. 127 H. R. 43d C. 2d Ses.] that "the assumption that river water is always charged with sediment to its maximum supporting capacity * * * has been shown by three years of accurate daily observations, at Carrollton and Columbus, to be utterly unfounded. Indeed, it often happened that the amount of sedimentary matter per cubic foot of water was greater in low than in high stages of the river, and never was there ever any fixed relation between these quantities. In other words, Mississippi River water is undercharged with earthy matter, and therefore no reasonable reduction of its flood velocity by an outlet will produce a deposit in the bed below."

By reference to pages 135 and 137 it will be seen that this extract contains an astonishing exaggeration. Instead of *three years*, the current and sediment observations only occupied *eight months* at Columbus and *one* year at Carrollton.

When we remember that the junior author of the report on the Mississippi River, was a prominent member of the Levee Commission, and that the senior author, as Chief of Engineers, warmly endorsed its report, it is difficult to reconcile this careless statement with the unusual scientific exactness which required four decimals to record their measurements of the current, (see page 244.) In this case the reader is converted to a false theory by being gravely as-

* This report was reviewed by me in the *Scientific American* supplement.

sured that it has been *demonstrated conclusively by three years* of daily accurate measurements at the upper and lower ends of the delta; and in the other case, he is captivated by the wonderful precision which tells him to the ten thousandth part of a foot, the varying distances which the flowing stream has traveled at different depths below the surface, in a second of time! As this statement is an inexcusable exaggeration, and as such exact determination of current volocities is utterly impossible by any known method of measurement, it follows that theories sustained by such testimony, cannot constitute advances in science.

On page 16 of the report of the Commission, we find the following: "It is asserted in the most confident manner that the river is flowing in a bed of its own deposit, with dimensions regulated in accordance with its own needs; and hence that the increased velocity resulting from the confinement of its flood-volume between levees will rapidly excavate its bed to a correspondingly greater depth."

"This reasoning, if true, would establish conditions singularly fortunate for the Levee system; but unluckily the wish has been father to the thought. Uncompromising facts show that the premises and conclusions are both erroneous for the lower Mississippi. Very numerous soundings, with leads adapted to bring up samples of the bottom, were made by the Mississippi Delta Survey throughout the whole region between Cairo and the Gulf. They showed conclusively that the *real bed*, upon which rests the shifting sand bars and mud banks made by local causes, is always found in a stratum of hard blue clay, quite unlike the present deposits of the river. It is similar to that forming the bed of the Atchafalaya at its efflux, and, as is well known, resists the action of the strong current almost like marble."*

The results of these soundings with prepared leads are not only unduly magnified in the above statements, but the reader is also misled by the assurance that they *conclusively proved* the existence of this marble-like clay.

On page 17 of this report this statement is made: "If we guard against these crevasses by raising and strengthening our levees, an elevation of the high-water mark proportional to the increased volume will be sure to occur."

"To contain a quart of water a vessel must have exactly the requisite number of cubic inches: and a like principle applies with equal force to water in motion."

This is quite a novel proposition. How a like principle can apply

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* It is assumed, that because the efflux of the Atchafalaya has not deepened under the action of the current, the clay bottom there will not wear and must be something different from the ordinary river deposits. A bottom of sand would remain just as permanent when the capacity of the efflux is adjusted to the volume of discharge. The cross section of the bed, whether of clay or sand, will inevitably increase or diminish with an increase or diminution of the volume.

to water in motion, I am at a loss to discover. The number of cubic inches in a quart cup is a question of space or volume only. When the water is in motion, *force* and *time* enter into the problem, and they make an elevation of the high-water mark exactly proportional to the increased volume, a simple impossibility, even if the bed of the stream should not deepen. That the height would increase with the volume, as in the case of a quart cup, is simply an absurdity. But when problems in dynamics are solved without considering the elements of *space* and *time*, and the profound mysteries of remote geologic epochs are unlocked with a greased sounding lead, we need not be surprised to learn that the most important questions in river hydraulics may be illustrated and explained with a quart cup.

If the bed of the river cannot yield, and all the crevasses in the levees are closed, the sides of the quart cup—or the levees, must be built up ten or eleven feet higher than ever before, and, therefore, the Levee Commission recommends, and the Chief of Engineers earnestly indorses, a system of levees at an estimated cost of $46,000,000, and all because the bed of the river has been conclusively proved by "an extended series of measurements," to be of an unyielding material.

A few years ago the Chief of Engineers of the U. S. Army, being equally as well convinced that the steamboat smoke pipes were, like the bed of the river, unyielding in their nature, and that they were too high to pass under the bridge which spans the Mississippi at St. Louis, accordingly recommended that a canal with a draw-bridge, through the bridge approach, to accommodate these unyielding smoke pipes, should be dug around the end of the bridge in the ancient geologic blue clay in Illinois, at a cost of over three million dollars! The fact that the river water was proved by "a glance at the two diagrams" to be always under-charged with sediment, was an assurance that the canal would be a success and would not silt up. But Congress did not look with favor on this plan. Doubts as to the unyielding nature of the smoke pipes were openly expressed, and while the canal plans and estimates were being prepared the lucky discovery was made that the whole difficulty could be avoided by putting hinges in the pipes; and so the three million of public treasure was saved, and the commerce of the river now flows under the bridge without let or hindrance.

PRACTICABILITY OF DEEPENING THE RIVER AND LOWERING THE FLOODS.

The inclined plane formed by the *surface* of the river from the highlands down to the sea is called its slope. The intensity or *degree* of force exerted by the water in its passage depends upon the steepness of this slope. The *amount* of the force depends upon the mass or

volume of the water and upon its velocity, the current being the result of the slope. The friction of the bed is the chief element which retards the current. The slope, the volume and the friction are therefore the chief agents which determine the speed of the current. Others modify it somewhat, but they need not be considered here.

Now, if the reader will bear in mind that the water is charged with sediment according to its velocity, and that it flows through a bed of precisely the same kind of material it is carrying in suspension, and and that if its velocity is increased it will take up a greater charge from its own bed, or if its current be slackened it will drop some of its charge in the channel, and add to its bed, he will understand the important part which the *speed* of the current performs in the problem. Through the whole alluvial basin from Cairo to the sea, the river must discharge as much sediment into the sea and over its banks, as its tributaries pour into it. If it discharged less, its channel would shoal up and its slope be steepened by the excess received from its tributaries.

If it carries more to the sea than is brought down into it from the tributaries, the excess discharged must be taken out of its own channel, and this would deepen it, and lower the slope. From this it is evident that there must be some means by which nature adjusts the speed of the current to suit the needs of the river. This is done by the relation which exists between the rate of current and the quantity of sediment carried in the water. If the velocity be too great the deepening of the bed follows. This lowers the slope and the current becomes less rapid. If the velocity on the contrary be too slow, deposition in the channel continues to take place until the river bottom is raised and the slope steepened, and a higher velocity is produced. These are the inexorable results of the relation between the current and its burden.

The river's slope, being the surface of the water, determines the height of the levees, and is therefore the vital question in the reclamation of the lands from overflow.

We see how the current alters the slope by the opposite processes of deposit and scour. We want to lower the slope to prevent overflow. When the current is too rapid, deepening is the process nature sets up in the bottom of the river, and gradually the slope is reduced and a normal current succeeds. To reduce the slope, we must temporarily increase the current. This can be done in two ways. Friction of the bed is the element which retards the velocity. Where the river is excessively wide, it will have more frictional resistance to overcome, and must there have a steeper slope. If we reduce its width at such place, the first effect will be an elevation of surface above. This will create a rapid current through the narrowed part, and it will be deepened there, and the elevation of surface above will then subside; but the current will still continue to be rapid, be-

cause the narrow and deep form of channel created will have less friction than the former wide one, and the rapid current will therefore continue to deepen the bed, until the original slope is so lowered that the current through the contracted channel is gradually reduced to the normal rate again. When this is done it will be found that the flood line or slope has been permanently lowered at that locality. This necessarily leaves the slope steeper immediately above the locality thus treated, and this induces a more rapid current, and consequent deepening of the bed, and lowering of slope still higher up. In this way the alteration of slope at one locality ultimately extends up to the head of the alluvial district. Of course this could not occur unless the most sensitive relation existed between the rate of current and the quantity of sediment suspended by it. Nor could it occur except where the bed of the river is formed of the same materials which it carries in suspension, or of materials easily eroded or moved by the current.

Another way to lower the slope is to increase the volume of water in the channel, because friction does not increase in an equal ratio with the volume. The greater is the volume, the lower is the slope, is a lesson taught by every part of the river, and by every outlet and bayou in the alluvial basin. This is because the proportion of friction to volume becomes less as the volume is increased, and, therefore, if the volume is increased, a lower slope will produce the normal rate of current, or that rate which will carry its charge of sediment to the sea without either loss or gain. It is impossible to maintain *permanently* any greater rate of current than will suffice to do this, in any sediment-bearing river in the world through its alluvial district. Bayou Atchafalaya at Red River carries a portion of the Mississippi to the sea with a fall of over six inches per mile, while the main river pursues a pathway more than three times as long, with a fall of less than two inches per mile. The greater friction in the smaller channel alone prevents a high rate of current through it. Its slope has been adjusted to maintain the rate required to discharge its waters and their earthy burden without injury to its own channel. If it were closed and its waters were compelled to flow in the main river, the first result would be an elevation of the surface and a more rapid current; a deepening of the bed would follow this, and a lowering of the slope would be the permanent result.

Lower levees would, of course, then be practicable. This teaches us that if we wish to lower the floods and deepen the channel, we must close the outlets and crevasses, and convey all of its waters through one channel to the sea. Humphreys and Abbot tell us precisely the contrary.

After an elaborate discussion on the effect of outlets and crevasses, they say (page 420): "The conclusion is then inevitable, that *so far as the river itself is concerned, they are of great utility.*"

The Levee Commission's report contains a table (page 59) from which it will be seen that from Cairo to Memphis (235 miles) there are 70 miles of crevasses and gaps in the levees, while many more exist below Memphis. It is well known that since the rebellion in 1861 these levees have been going to destruction.

Certainly a sufficient number of outlets and crevasses have been existing and occurring here in the last seventeen years to test their utility and the value of the opinion of these gentlemen on the subject.

Major Suter, U. S. Engineers, has made the most recent survey of the river, and in his report, 1875 (Ex. Doc. 19, page 16, 43d Congress), he says: "Within the memory of living pilots the shoal water has extended down from Plum Point, one hundred miles above Memphis, to Lake Providence, fifty miles above Vicksburg, a total distance of 450 miles; and as these disturbing causes will act with more vigor every year, it is time that we should fairly face and realize the fact that, unless speedily checked, there are natural causes at work which will eventually destroy the navigability of the Mississippi and its tributary streams." Comment is unnecessary.

Since 1842 two large outlets have occurred, from artificial causes, through the narrow strip which separates the river from the Gulf, a few miles above the head of the passes. Through these about one-fifth of the river is now discharged. They are known as Cubitt's Gap and The Jump. Surveys made in 1875, when compared with that of Talcot's, made before they occurred, have revealed the fact that the depth of the river below the lowest one has been reduced from over forty to thirty feet, and *the size of the river bed is fully one-quarter less* than it was before these crevasses occurred. I called public attention to this startling fact, to show that crevasses *do* cause shoaling in the river channel. Here is the explanation for this deposit, given by Gen. Humphreys (see Appendix L, H. and A.'s Report, 1876): "During the low-water stage of the river there is a stratum of salt water many feet thick at the bottom in the passes and in the wide part of the river at the head of the passes, and extending above that point some distance, which has but little current either way compared to the current of fresh water on top of it; the earthy matter suspended in the river water falls upon the bottom of the river thus occupied by salt water, just exactly as it falls upon the bottom of the Gulf out at sea beyond the bars, and during the low-water stage a deposit is thus made on the bottom of the river."

On page 420 we are told that "there is no evidence that any filling up of the bed ever did occur in consequence of a high-water outlet; and, moreover, that *it is impossible that it ever should occur*, either from the deposition of sedimentary matter held in suspension, or from the accumulation of material drifting along the bottom."

In view of the stubborn fact that this enormous shoaling *has oc-*

curred since Cubitt's crevasse was made, it is plain that the above positive statement must be taken *cum grano salis*. Indeed, it seems important for the credit of its authors that it be taken with a very large quantity of salt; for it appears that if there is a stratum of salt water under the river water, a shoal *will* occur below a crevasse. The feeblest current, then, according to Gen. Humphreys, is not, *with salt under it*, capable of carrying so much sediment as the most rapid current; and the distribution of the sediment appears to be controlled by law if it has brine below it. The river water, then, ceases to be "always undercharged," and the relation between cause and effect is restored. The virtue of salt water is truly marvelous. "Old assumptions which experimental investigation has long since shown to be utterly unfounded in fact" become demonstrated truths, if a stratum of it be under the river water.

On page 415 of the report of Humphreys and Abbot the following quotation is made from an article published by Major (now General) J. G. Barnard, U. S. Engineers, in *Debow's Review*, in 1850:

"I find this principle laid down in the work of Frisi, "On Rivers and Torrents," which was placed in my hands by W. S. Campbell. He quotes and confirms the rules established by another engineer, Guglielmini, which are that "the greater the quantity of water a river carries, *the less will be its fall*," and "the greater the force of the stream, the less will be the slope of its bed." And, again, "the slope of the bottom in rivers will diminish in the same proportion in which the body of water is increased," and *vice versa*. These rules have their explanation in the facts that the beds of rivers, of the character above mentioned [like the Lower Mississippi], are capable of resisting, unchanged, only a certain velocity of current; and, on the other hand, that the sedimentary matter contained in the river water requires a certain degree of velocity to keep it in suspension. From the counteracting tendencies of the above two causes, a mean becomes established, at which the current ceases to deposit its sediment, and the bottom ceases to be abraded; in other words, the bottom becomes permanent. But if, from any cause, such as throwing off a portion of the water through a waste-weir, the velocity of the current is diminished, it is no longer able to maintain its sediment in suspension, but will continue to deposit in its bed, until, through the elevation of the bed, its velocity again becomes what it was before it was disturbed, sufficient to maintain its sediment in permanent suspension."

As this proposition is fully sustained by the Columbus and Carrollton experiments, and is conclusively proved by the phenomena presented all through the alluvial basin, the summary manner in which it is disposed of by Humphreys and Abbot is amusing. They say:

"It will be noticed that two important assumptions are necessary to support this reasoning: First, *that the bottom of the Mississippi is composed of its own alluvion, which can be readily acted upon by the current*; and, second, that its water is *always charged with sediment to the maximum capacity allowed by its velocity*.

"Throughout the whole distance from Cairo to Fort St. Philip the

true bed consists of a tenacious clay which is unlike the alluvial soil, wears slowly under the strongest currents, and is proved, by conclusive evidence, to belong to a geological formation antecedent to the present. This disposes of the first assumption.

"We come, then, to the second assumption, viz.: that the water is at all times charged with sediment to the maximum capacity allowed by its velocity. * * * A glance at the two diagrams (plates XII. and XIII.) is sufficient to demonstrate the falsity of the assumption that Mississippi water is always charged with sediment to the maximum capacity allowed by its velocity. * * * The second assumption is, then, as untenable as the first."

THE RELATION BETWEEN THE CURRENT AND SEDIMENT IS EXCEEDINGLY SENSITIVE.

Owing to the great width of the river at the head of the passes, the depth at the entrance into each pass is much shoaler than it is in the pass. South Pass is about 700 feet wide and over 30 feet deep, but the water entering it was about 2,800 feet wide half a mile above its entrance, and at this place the channel was but 14 feet deep. To concentrate this 2,800 feet into a narrow and deep channel, I erected, with other more substantial works, a dam or willow screen 1,900 feet long across the current on the eastern side of this shoal. The dam consisted of a single thickness of willow mattress held in a vertical position by piles, the willow work being only two feet thick, and the depth of water being from 12 to 16 feet. Of course the current passed through the willows with but little hinderance. It was not intended to be an impervious dam, and the whole structure was only strong enough to resist stormy weather. It was built with the practical knowledge that a *very slight* retardation of the current *will* cause a deposit. Two floods caused so great a deposit both above and below it that a small row boat can not now get to the dam at low tide. In another season or two, vegetation will probably cover this deposit and extend many hundred feet above the dam, and an area of more than one hundred acres of dry land will occupy the space between the dam and the main land below. The channel through the shoal is now twenty-two feet deep at low tide.

In the Department of Public Works at St. Petersburg I was shown a device similar to a Venetian blind, formed with small ropes and wooden slats, that was said to have been successfully used on the Volga for the same purpose as the willow dam I have described.

These results can be explained on no other theory than that the amount of sediment carried is strictly regulated by the velocity of the current. The burden can only be carried by the expenditure of force. Nature adjusts the quantity to the force, and if we absorb any portion of the force even by the resistance of a porous willow dam, less force will remain to carry the burden, and some of it must then fall to the bottom.

It is simply impossible that the work done, or load carried, can be greater than the force expended, or that the effect can be greater than the cause; and hence we can not compel the force that is required by nature to transport the sediment to do any other work, even so much as the turning of a mill wheel, or absorb any part of it by the friction of a dam made with open willow twigs, or even with one made with a fish net, without lessening, by so much, the force which is being expended in transporting the sediment. If we do, a deposition of a portion of the load must result, and it must continue to fall until, by the raising of the bed, a new regimen is established.

[The following criticism of the review of Humphrey and Abbot's Report on the Physics and Hydraulics of the Mississippi River, appeared as an editorial in the *Engineering and Mining Journal*, of New York, September 7th, 1878:]

PHYSICS AND HYDRAULICS OF THE MISSISSIPPI RIVER.

Mr. James B. Eads, C. E., contributes to the September number of *Van Nostrand's Magazine* a review of the report of Humphreys and Abbott on this subject, which was made in 1861, and has recently been republished by the Government. Of course Mr. Eads is justified in criticising this report, and disproving its conclusions if he can. The style which he may choose to adopt in doing so is a matter of taste and policy. We think that he would have shown both bad taste and bad policy in assuming the tone of contempt and sarcasm, even if his contempt had been justified and his sarcasm well directed. But neither of these conditions is fulfilled, and the attempt of Mr. Eads to show up two eminent, pains-taking, skillful and disinterested engineers as charlatans, ignorant of the first principle of mechanics, recoils upon himself.

The Mississippi itself is not muddier than his argument. He sets himself to controvert two propositions, which are fatal to his own theories and schemes. The first is, that the greatest velocity of the current of the Mississippi does not correspond to the greatest proportion of sediment carried by it. This was proved by Humphreys and Abbott, through experiments showing that the quantity of sediment per cubic foot of water is not proportional to the velocity of the water. But Mr. Eads claims that because the greatest velocity is coincident, other things being equal, with the greatest volume of the stream, therefore the basis of comparison should be the total quantity of sedi-

ment carried by the stream. The absurdity of this claim is apparent at once. The practical question is not whether a big river carries more sediment than a small one, but whether the same amount of water moving rapidly carries in this case more sediment than when it moves slowly, and whether the amount of suspended matter is proportional to the velocity. Evidently what is true of an average cubic foot of the mass of water is true of the whole mass.

Here is a specimen of Mr. Eads's reasoning on the subject:

"If the mean current at Columbus was six feet per second, an entire section of the river six feet long must have moved at that place and time through the space of six feet; and the force expended was therefore the entire force due to the motion of this whole section during that second * * * * * If we multiply the cross-section of the river, in square feet, by the current in linear feet per second, the product would be the number of cubic feet in the section; and these multiplied by the number of grains of sediment in one foot, would give the proper amount for comparison with the current."

Mr. Eads does not seem to see that if the quantity of water passing down the river remained the same, the cross-section would diminish in proportion to the increase of its rapidity; and hence, that the result of his calculation would be exactly the same as that of a calculation based upon a single cubic foot. If Q be the number of cubic feet passing a given point per second, and V be the velocity in linear feet per second, $\frac{Q}{V}$ will be the cross-section. So long as Q is constant, any increase in V will proportionally reduce the value of $\frac{Q}{V}$. Now the quantity of water passing down the Mississippi is supplied by Nature. The question therefore is, if this quantity were made to move faster, would it carry a proportionately larger quantity of sediment? Messrs. Humphrey and Abbott have demonstrated that the whole mass would not do so, because each cubic foot of foot does not. Mr. Eads takes unnecessary pains to construct from their data a new diagram, showing that, although the *proportion* of sediment does not vary as the velocity, the total amount of sediment does vary (roughly) as the total amount of water; and as these observations were made upon changes in velocity due wholly to the varying supply of water, and not to change of grade, he establishes in this way an apparent relation between total sediment per second and velocity. But if the velocity were made to vary by any other cause than the quantity of supply, this relation would disappear. Thus, s being taken as the grains of sediment per cubic foot of current, Messrs. Humphreys and Abbott show that s bears no regular relation to V. Whereupon Mr. Eads, multiplying s by Q, which is in this case a function of V, triumphantly demonstrates that sQ does vary as Q (more or less), and therefore as V!

If the quantity of sediment per cubic foot were absolutely uniform

at all velocities, then Mr. Eads's table would show absolutely parallel curves and his demonstration would be perfect. Let us suppose, for instance, that the Mississippi carried a saturated solution. Then s would be perfectly independent of V; and yet by Mr. Eads's method sQ would vary exactly as V—*quod erat demonstrandum!*

In the second part of his essay, Mr. Eads assails the statement that the Mississippi bottom is composed of blue clay, older than alluvion, and exceedingly tenacious. This he declares to be an opinion hastily drawn from insufficient evidence. Aside from his silly attempts to ridicule it, he succeeds in showing that the proofs are not as numerous and conclusive as they might be made by further observations. Unfortunately, his exhibition of conceit and ignorance on elementary questions does not render his challenge of any scientific proposition a weighty one. Before laying down the law on such subjects, he must be elevated to the bench. Just now, as it happens, it is Mr. Eads and his theories that are on trial. He refers to the results of operations at the mouth of the Mississippi, as though they had completely vindicated his judgment and dumbfoundered his critics. This cool audacity may impress some minds as the sublime confidence of genius, and the perfect consciousness of power and knowledge. Those who have watched closely the career of Mr. Eads, while they recognize his enterprise and perseverance, and make allowance for his arrogance of temper, are not ready to accept his sanguine declarations and prophesies in lieu of facts. With regard to his boasted success at South Pass, the cardinal difficulties foreseen by his critics have yet to be encountered; and he would be wise not to make quotations from the history of his triumph before the book has been written. *

Note.—A notice at the head of the editorial matter in the *Engineering and Mining Journal*, informs the public that articles signed thus * are written by Mr. Rossiter W. Raymond, Ph. D.

[*The following in reply to the above criticism appeared in the Engineering and Mining Journal, October 26, 1878:*]

Editor Engineering and Mining Journal:

SIR—As your notice on the 7th ultimo, of my review of Humphreys and Abbot's report on the "Physics and Hydraulics of the Mississippi River," contains some important mistakes, I respectfully ask the privilege of pointing them out to your readers.

You say: "He sets himself to controvert two propositions, which are fatal to his own theories and schemes. The first is, that the greatest velocity of the current of the Mississippi does not correspond to the greatest proportion of sediment carried by it. This was

proved by Humphreys and Abbot, through experiments showing that the quantity of sediment per cubic foot of water is not proportional to the velocity of the water."

This is a mistake. On the contrary, they did not prove it but only asserted it. I, however, proved by their own data, that the greatest velocity *does* correspond to the greatest quantity of sediment carried by it, and I will presently show that you admit it.

You fall into a *second* mistake in supposing that they *could* prove the contrary by showing that the quantity per cubic foot is not proportional to the velocity, for the simple reason that the sediment in a cubic foot is not the proper quantity to compare with the current to demonstrate the relation in question. The quantity in a cubic foot cannot always be proportional to the velocity, because the suspending power of the current is modified by the depth of the water (as well as by other causes), and the depth of the stream is by no means uniform. I endeavored, on page 9, of my review, to explain why the depth influences the power of suspension.

You say: "But Mr Eads claims that because the greatest velocity is coincident, other things being equal, with the greatest volume of the stream, therefore the basis of comparison should be the total quantity of sediment carried by the stream." This constitutes your *third* mistake. I think you misunderstand the reason for such comparison. It is not because the greatest volume and greatest velocity are coincident, for they are not always so. The relation exists whether they are coincident or not. It is simply because the total force expended in one second should be compared with the total work done by that force in that second, and not with a single unit of one of the four elements of the work. These elements are *force, matter, space,* and *time,* and in their comparison *space* and *time* are totally neglected, as is fully explained in my review. Because the relation did not appear in this comparison, they forthwith declared that none exists between the current and the sediment it carries. Their comparison was meaningless as it would be to compare a bushel of grain with a linear inch of the bottom of a bushel measure. The elements of diameter and depth being ignored, we might just as well assert that there was no correspondence between the quantity of grain and the measure in which it was meted. There was no harm, however, in making such comparison. The harm came from erecting on it absurd and dangerous theories to mislead others. The idea advanced and supported by them, that "Mississippi water is undercharged with earthy matter, and therefore no reasonable reduction of its flood velocity by an outlet will produce a deposit in the bed below," is a pernicious error, resting upon their comparison of the current *per second* with the sediment found in a cubic foot of the water at the time. They triumphantly refer to their diagrams exhibiting the results of these comparisons, to prove this statement!

Your *fourth* mistake consists in declaring that "The absurdity of this claim [my method of comparison] is apparent at once." This you proceed to prove in the following manner: "Mr. Eads does not seem to see that if the quantity of water passing down the river remained the same, the cross-section would diminish in proportion to the increase of its rapidity; and hence, that the result of this calculation would be exactly the same as that of a calculation based upon a single cubic foot. If Q be the number of cubic feet passing a given point per second, and V be the velocity in linear feet per second, $\frac{Q}{V}$ will be the cross-section. So long as Q is constant, any increase in V will proportionately reduce the value of $\frac{Q}{V}$. Now the quantity of water passing down the Mississippi is supplied by nature. The question therefore is, if this quantity were made to move faster, would it carry a proportionately larger quantity of sediment? * * Mr. Eads takes unnecessary pains to construct from their data a new diagram, showing that, although the *proportion* of sediment does not vary as the velocity, the total amount of sediment does vary (roughly) as the total amount of water; and as these observations were made upon changes in the velocity due wholly to the varying supply of water, and not to changes of grade, he establishes in his way an apparent relation between total sediment per second and velocity."

Now, having admitted that I established this relation "in this way," and it being an impossibility to show it in this way, or in any other way, if it did not exist, I demonstrate the proposition you declare to be so absurd. I show it to exist *in their own data*, which is precisely where they said it did not exist. I prove they are in error by their own testimony, and you confess that I do so, while trying to expose what you politely term my "exhibition of conceit and ignorance on elementary questions."

Your *fifth* mistake consists in asserting: "But if the velocity were made to vary by any other cause than the quantity of supply, this relation would disappear."

In 1875, the river at South Pass flowed out of a channel about 800 feet wide and 35 feet deep, into the sea, and spreading out like a fan, it crossed the crest of the bar two miles further out, with a width of about 5,000 feet, and a depth of only 8 feet in mid-channel. This fan-shaped discharge has been contracted to a uniform width of 1,000 feet by two parallel jetties extending from the banks of the stream out into the deep water in the sea; hence $\frac{Q}{V}$, or the cross-section of the volume at the crest of the bar was reduced; V was increased, while Q remained practically constant.

These conditions, therefore, fulfill your illustration. Let me repeat your words: "The question, therefore, is if this quantity [moving

down the pass] were made to move faster [as it does between the jetties], would it carry a proportionately larger quantity of sediment? Humphreys and Abbot have demonstrated that the whole mass would not do so, because each cubic foot of it does not." And nature has demonstrated that Humphreys and Abbot were sadly in error; for it caused the water, already charged with sediment when it entered the jetty channel, to take up a still greater quantity because of the higher velocity imparted to the mass, and it was thus enabled to remove, in a little over two years, about 5,000,000 cubic yards of the deposit between the jetties. The velocity was not due, in this case, to volume, but to "change of grade." Could it be possible for this vast mass of sediment to be taken up by the water as it passed through the jetties and yet not increase the quantity already in each cubic foot of it?

You proceed to say: "In the second part of his essay, Mr. Eads assails the statement that the Mississippi bottom is composed of blue clay, older than alluvion, and exceedingly tenacious. * * * Aside from his silly attempts to ridicule it, he succeeds in showing that the proofs are not as numerous and conclusive as they might be made by further observations."

To form a correct judgment of the importance of this question, and to appreciate the frankness of this courteous admission, it should be stated that a recommendation is now before Congress to expend forty-six million dollars for a new system of levees, to have a maximum height of eleven feet above the highest flood known on the Mississippi; and that this recommendation is made by General Humphreys, Chief of Engineers, and a Commission of which General Abbot was a member, and that the gist of the reasons which induced these engineers to recommend these enormous levees is contained in the following extracts from the report of the Commission (pages 16 and 17): "Very numerous soundings, with leads adapted to bring up samples of the bottom, were made by the Mississippi Delta Survey throughout the whole region between Cairo and the Gulf. They showed conclusively that the *real bed*, upon which rest the shifting sand-bars and mud-banks made by local causes, is always found in a stratum of hard blue clay, quite unlike the present deposits of the river. It is similar to that forming the bed of the Atchafalaya at its efflux, and, as is well known, resists the action of the strong current almost like marble. Clearly, then, the bed of the Mississippi cannot yield." They proceed to say, therefore: "If we guard against these crevasses by raising and strengthening our levees, an elevation of the high-water mark exactly proportional to the increased volume will be sure to occur."

In my review I explain (pages 15 and 16) the cause of a phenomenon that is presented by every sediment-bearing river in the world: namely, the greater is its volume, the lower is its flood-line or sur-

face-slope. To close the gaps and crevasses in the present levees, must increase the river volume, and hence it must lower its slope or fall per mile; for unless its bed is almost like marble, it must deepen under the action of the increased current created by the retention of its flood-waters; and in that event, such of the levees as are now effective must then prove higher than necessary. If crevasses occur, the volume is diminished, the current becomes more sluggish, and deposits are thrown down, shoals are increased, and the river gradually assumes a steeper slope. Thus, higher levees become a necessity, and the navigation is made more difficult. Therefore, if this unyielding clay is a myth, the complete repair of the present levees, which will cost probably not over four million dollars, will be sufficient to protect the lands, and their repair must incidentally benefit the navigation.

From this it is evident that the relation of current to suspended sediment, and the character of the material composing the river-bed, are the two grand facts upon which rests the solution of the problem of reclaiming the alluvial lands, and deepening the channel of the Mississippi.

The question of the existence of this unyielding clay is therefore, one of immense practical importance, not only as forming the basis of a proposition to expend forty-six million dollars, but as a vital question in the improvement of the navigation of the river.

In the thousand miles between Cairo and New Orleans there is not a stretch of river fifty miles long in which I have not stood upon the bottom beneath the shelter of the diving-bell, and examined the character of its bed. These examinations embraced many hundred localities, and in none did I find any trace of this marble-like clay. I therefore felt certain, notwithstanding the positive assurances of these gentlemen to the contrary, that this clay was a myth. I examined the report however, to see if its existence had been verified by borings "beneath the shifting sand-bars and mud-banks," but to my surprise found that none had been made during the survey. I then carefully read again Chapter II., where, in the words of the text, "the results exhibited in Appendix C are discussed."

The elaborate discussion of these results, in that chapter, by which this imaginary clay is shown to belong to a remote geologic epoch, failed to satisfy me, and I determined to undertake the labor of analyzing for myself the record in in Appendix C, to learn the exact truth. There I found that between Cape Girardeau, Mo., and Vicksburg, Miss., only eleven lines of soundings had been run across the river at different places in this entire distance of 650 miles. The number of soundings on each line averaged about fifty. On four of these lines no samples at all were obtained; and on the other seven lines a total of only thirty-five samples were secured! Astonished at this small number, I turned to the text and re-read the impressive

statement, under the imposing head of *Geology of the Channel*, that "A knowledge of the river-bed is of the highest practical importance, * * * and great efforts have been made to acquire it." Unconsciously I contrasted these few samples with these great efforts, and felt sure I had gone into the wrong appendix. Indeed I felt morally certain of it, when I read the corroborative statement on page 14, that "great pains were accordingly taken to collect specimens of the bed wherever soundings were made." Here were at least 550 soundings and only 35 specimens! When I remembered that Congress had been urged by these gentlemen to expend $46,000,000, because "*very numerous soundings*" with prepared leads had *conclusively* proved that "the bed of the Mississippi cannot yield," I was convinced that Appendix C was not the place to look for all of the facts. I therefore examined all the appendices from A to M inclusive, and looked through the four or five hundred pages of the report, for additional results of soundings in this 650 miles, but in vain. Pursuing this interesting investigation still further, however, I examined the "uncompromising facts" presented by this small array of specimens supporting the affirmative side of this ancient geologic and marble-like, hard blue-clay question, and was amazed to find that Appendix C actually shows that twenty-five of these samples *were nothing but sand!* Three of them were sand mixed with clay, leaving but *seven solitary specimens of clay*, taken from the end of a greased sounding-lead, to establish the geology of the bed of six hundred and fifty miles of the Mississippi! Only seven bits of clay to support these positive assurances and grave statements, and to sustain a recommendation to expend $46,000,000, to build levees eleven feet higher than the great flood of 1858!

These are *the facts* developed in my review, and you have not had the temerity to dispute them. Yet you say: "The attempt of Mr. EADS to show up two eminent, painstaking, skillful, and disinterested engineers, as charlatans, ignorant of the first principles of mechanics, recoils upon himself."

You have wholly mistaken my motives in reviewing their report. I have neither time nor inclination to show up the charlatanry of any one. My object was to correct, if possible, the injurious effect of certain very extensively-accepted errors, and thus remove the chief obstacle to the adoption of a correct system for the improvement of the river, and the reclamation of its alluvial basin. To disprove their theories and conclusions respecting the transportation of sediment, it was necessary to show that problems in dynamics can not be solved without bringing into them the elements of *space* and *time*. These they had neglected, and therefore, when I took their tables and brought these elements into the problem, their own data proved precisely what they had denied; namely, that there is an intimate, direct and constant relation between the velocity of the current and the

burden of sediment it carries in suspension; and that this relation is modified by the depth of the water.

My declaration that the river-bed is composed of its own deposits, and that the increased current resulting from the confinement of its entire flood volume between levees will cause it to excavate a deeper channel and thus prevent any increase in the high water mark, is met by the following, on page 16 of the report of the Levee Commission: "This reasoning, if true, would establish conditions singularly fortunate for the levee system; but, unluckily, the wish has been father to the thought. Uncompromising facts show that the premises and conclusions are both erroneous for the lower Mississippi. Very numerous soundings * * * were made by the Mississippi Delta Survey," etc., etc. Being thus squarely confronted with *uncompromising facts* I was compelled to go to the facts themselves, and my review shows the result of my investigation in that direction.

Aside from the insignificant number of specimens of clay which constitute these *uncompromising facts*, a moment's reflection must show the absurdity of basing the existence of this marble-like clay upon such testimony as a greased lead could bring up from the bottom of the Mississippi, even if the samples had been numbered by thousands. If this supposed clay yields but slowly to the strong current it would certainly not yield samples of its substance to the grease on a sounding-lead. Nor is there anything in the record of the soundings to show that the specimens were different from the ordinary blue-clay deposits of the river, which are thrown down from its waters wherever the current is very sluggish during low-water seasons. The only description of the specimens in Appendix C is contained in the words "*clay*," or "*blue-clay*." Besides all this it is plain that the specimens adhering to the end of a tallowed plummet can not possibly give any evidence whatever of the character of the material one inch below the surface that was in contact with the tallow.

Respectfully, etc., JAMES B. EADS.

RIGGS HOUSE, WASHINGTON, October 10th, 1878.

MINORITY REPORT

Giving Reasons for Withholding Signature from the Annual Report of the Mississippi River Commission.

General Q. A. Gilmore, U. S. A., President of the Mississippi River Commission:

SIR,—I feel compelled to withhold my signature from the last annual report of the Mississippi River Commission, as I differ with the views expressed therein on the following important points:

LEVEES.

In the report the following paragraph occurs:

"It is considered by all that levees, by confining the flood waters of the river within a comparatively restricted space, do tend, in some degree, to increase the scouring and deepening power of the current. But the extent and potency of their influence in the improvement of the low-water channel, in respect to which, for the purpose of navigation merely, improvement is most needed, and their value, for that purpose, as compared with other methods of improvement, and as compared with their cost, are regarded as subjects requiring further observation and study, and the accumulation of further and more comprehensive data, before final conclusions can be reached concerning them."

The effect of this paragraph is to weaken the recommendation made by the Commission in its report of February, 1880, with regard to the importance of closing the gaps in the levees. The report of 1880 states that—

"The views of the several members, however, are not in entire accord with respect to the degree of importance which should be attached to the concentration of flood waters by levees as a factor in the plan of improvement of low-water navigation which has received the unanimous preference of the Commission."

My views regarding the important agency of the levees in improving the *low-water* channel of the Mississippi were not expressed in that report with a degree of emphasis which I then desired, and I am unwilling to commit myself now to any expression in the present report, which, in the slightest degree, tends to throw a doubt upon *the necessity* of, or to justify any furthey delay in the closing of these

outlets. On the contrary, I deem it proper to urge with redoubled force the absolute necessity of their immediate closure.

From quotations hereinafter made from the previous report of the Commission, it will be seen that it relies upon the increased volume of discharge for scouring more deeply the bed of the river and lowering its floods. The loss of its volume through outlets or crevasses is fully recognized in that report, as the cause of the deposition of sedimentary matters in the bed of the river, by which its flood surface is raised from year to year.

Observations made by the Commission plainly show that the effect of the present gaps in the levees has been to raise the flood-line of the river many inches above any hights previously attained within the 700 miles in which they exist most numerously, between Natchez and the mouth of the Ohio River. Within this distance there have occurred during the last eighteen years innumerable crevasses, aggregating, in 1875, a length of about 100 miles, and throughout this part of the river the deposits have raised its bed so much as to greatly injure navigation, and to cause smaller floods to rise to heights never before attained.

This question is of such vast importance, and in view of my dissenting from the report of the Commission, I trust that I will be pardoned for explaining, at some length, the general principles underlying the plan of improvement recommended by the Commission, and the relation which the levees have to that plan. It should be borne in mind that this plan is only applicable to the rectification of a sediment-bearing river, and not to rivers flowing through rocky beds, and whose waters are clear. It should be especially noted, also, that this plan, when fully executed, will render the further use of levees, almost, if not entirely, unnecessary. A more ready understanding of the principles upon which it is based will be had by first briefly describing the formation of the lower or main alluvial basin of the river.

This basin extends from Commerce Missouri (a few miles above the Mouth of the Ohio), to the Gulf of Mexico, and has an average width of about sixty miles. Its length is about six hundred miles in a direct line, and it contains about 34,000 square miles, or an area equal to that of the State of Indiana. At the upper end of the basin a spur of the Ozark Mountains has been cut through by the river at the town of Commerce, and through this, over a rocky bottom, six or eight miles in length, the Mississippi now flows. Forty miles above Cairo, on the Ohio River, the same spur has been cut through by that tributary. Throughout this entire basin, bounded by highlands on each side, we have every reason to believe that an estuary of the Gulf of Mexico once existed similar to the Gulf of St. Lawrence; or to the Rio de la Plata, which is now being filled and built up by the immense mass of deposits annually poured into it by the Parana and

Paraguay Rivers. The floods of the Mississippi River, being highly charged with sedimentary matter, have filled this ancient and extensive estuary with alluvial deposits to the height of about three hundred feet above the sea at the upper end of the basin. The surface of the land thus made by the river has a comparatively regular descent from the upper end of the basin to the Gulf, being at Gaines' Landing, midway to the Gulf, about one hundred and forty feet above the sea. Through these deposits the river winds its tortuous course in a channel about 1,150 miles long.

Experience and observation prove most conclusively that the quantity of solid matter which the water of the river is able to hold in suspension is strictly regulated by the velocity of the current. Therefore, during the natural process of this land formation, whenever the flood waters escaped over the banks of the channel, the loss of current in the water thus escaping caused the sandy or heavier portions of the solid matter held in suspension in it, to settle almost immediately on the submerged banks; while the argillaceous and lighter portions, which take longer to settle, were carried back by the feebler current to the swamps or lower lands, on which they were deposited over a much more extensive area. These lighter matters now constitute the blue and other colored clay strata which are found in all parts and at all depths of the basin. The river banks were thus kept constantly higher than the lands more distant from the stream. Before any levees were built on them they were usually from ten to fifteen feet higher than the lands one or two thousand yards distant from the river.

The size of the flowing volume of any river constitutes as will be seen hereafter, a very important element in determining the velocity of its current, and as the loss of volume over the natural banks has the effect of producing a more sluggish current in the main channel, a deposition of sediment resulted wherever this loss occurred.

In this manner the bed of the stream, during each successive flood, was built up higher and higher, while the water escaping over the banks built them up also. Thus the river and its banks were both gradually elevated above the neighboring lands until some important breach occurred in one or the other bank, and caused the river to seek a new channel through or over the lower lands. Illustrations of this process are frequently occurring at this time in the lower part of the basin. Sixty miles above the mouth of the river its flood surface is now seven or eight feet higher than the mean level of the Gulf, and through this sixty miles it flows to the sea between narrow banks that have been elevated by repeated overflows above the sea-level. From time to time the river has broken through these narrow embankments and found a steeper and shorter route to the salt water. Through such new route its heavily-laden waters bear immense quantities of sediment, which is deposited in the Gulf at the

mouth of the outlet, because the current can carry it no farther. About thirty-five miles above the mouth, one of these outlets, known as "The Jump," occurred about forty years ago. It has already formed over a hundred square miles of territory upon which rice plantations exist, and on which trees are growing larger than a man's body. From six thousand acres of this land, purchased from the State of Louisiana, were obtained nearly all of the willows used in the construction of the jetties. The gradual enlargement of this sub-delta has so lengthened the outlet and flattened the surface-slope of its branching channels that the current from the river through them, even in flood-time, is now too sluggish to carry the heavy sedimentary matters of the main river by that route to the sea, and hence this outlet is gradually closing up. When it first occurred the water in it was 100 feet deep; now it is scarcely four or five.

During this land-building process of the river, outlets were doubtless formed, from time to time, throughout the entire six hundred miles of the basin, in a similar manner to the one described at "The Jump." Occasionally the conditions were such as to cause the entire stream to forsake its old channel, and in this way it was enabled to distribute its deposits throughout the whole width of the basin from bluff to bluff. Cut-offs and crevasses facilitated this distribution, and the elevation of the bed and the banks of the stream gave it the ability to maintain a sufficient height above the adjacent lands to send its earthy matters many miles away from its channel, while the unstable character of its banks enabled it to change its location from time to time, and thus to cover every part of the basin with its deposits.

Levees stop this land-building process, because they restrain the floods within the defined channel of the river, and so long as they are intact it is impossible for the banks or the bed of the river to be built up to greater heights by the natural process just described. It is an error completely, and often disproved, but still repeatedly advanced by misinformed persons, that rivers confined between levees have a tendency to have their beds elevated, and, as a consequence, to need a corresponding elevation of the levees. The Po and the Rhine and other rivers in Europe effectually disprove such assertions. Their channels have been deepened and their floods lowered as a consequence of perfect levees, and this, it will be presently seen, is an inevitable result of the laws which control the phenomena of sedimentary streams, wherever they flow in channels made through their own deposits. These principles or laws I will now endeavor to explain.

The term "slope of the river" is used by engineers to indicate the inclination which the surface of the flood bears to the sea-level. When "*the slope*" is referred to without qualification, it means the *flood line* at the various points along the river, and is synonymous

with the term "the fall of the river per mile." It has no reference to the slope of *the bottom* of the river. One end of the slope is unalterably fixed by the Gulf of Mexico. Other points in its line may be lowered or elevated to a certain extent by natural or artificial causes.

The force which produces the current is the fall of the water from a higher to a lower level, and the slope is an indication of the amount of this force. Other conditions being the same, the steeper the slope the more rapid will be the current.

The chief element which retards the current is the friction between the water and the bed of the stream. This friction increases as the surface in contact with the water increases, and is, therefore, greatest where the width is greatest, and conversely it is least where the width of the channel is least. Hence it is evident that the velocity of the current may not only be increased by increasing the slope, but also by decreasing the friction. It must be remembered that nearly all of the sedimentary matter transported by the water is carried *in suspension*, and that the quantity carried is in proportion to its velocity. Only a small quantity of it is rolled along the bottom. Hence, if the current be checked when its waters are heavily charged with this sediment (as they always are in flood time), *a deposition of a portion of their burden becomes inevitable*. No fact in connection with the river is more thoroughly established than that *the current in flood time cannot be checked in the slightest degree without causing a deposition of some part of the sediment.* Screens of iron wire with meshes one foot square, placed across shoals in the Missouri river, have sufficed to retard the current enough to cause deposits 16 feet deep to be formed during one flood, and in this simple manner new banks have been developed in excessively wide parts of that river to deepen its channel and lower its slope. Willow screens, first used at the jetties at the mouth of the river, for the same purpose, raised the bottom during one flood, over a large area at the head of the passes where it was from 12 to 16 feet deep, almost to the surface of the water, and 70 or 80 acres of land covered with vegetation are now to be seen on the eastern side of the upper end of the South Pass channel that has been thus formed.

I have named three controlling principles which are present in every problem presented by the characteristic phenomena of the river. Each one of these is very simple in itself. It is, however, absolutely necessary to remember each of them to fully comprehend the subject, and to be able to recognize the respective influence of each in creating these phenomena. I will briefly repeat them to more strongly impress their importance. The *first* is the force producing the current. This force is simply the result of the fall of the river from a higher to a lower level. The *second* is the frictional resistance of its bed. The *third* is the intimate relation between the quan-

tity of sediment carried in the water and the velocity of the current. If we increase or decrease the current from any cause, we increase or decrease the quantity of sediment carried by the river. We can increase or decrease the current temporarily by either of two methods; namely, by altering the slope, or by altering the frictional resistance. Therefore, by these two methods the scouring and depositing effect can be produced. If we increase the current during the floods we produce a greater deepening and enlarging of the channel through the shoals and they are left in better condition during low water, and at the same time we ultimately lower the height of the floods. If we decrease the current we produce shoals and higher floods.

The river, from Commerce to the Gulf, between the levees, is simply a grand trunk, into which is poured all of the sedimentary matters of the tributaries. This trunk must discharge as much sediment as it receives, or that which it does not discharge must be left in the channel and thus injure navigation. If it discharges more than it receives, the excess must be taken out of the bed of the channel, and it will be deepened thereby and the floods will be lowered. Hence it follows that by the process of deposit, or scour, the river has the ability to produce a current capable of carrying its sedimentary burden, without loss or gain, to the sea. This velocity of current we may call the *normal* current. In seasons of great floods the *normal* current will be more rapid than when the waters are less highly charged with sediment. This normal current is produced by the river itself as a result of these three controlling principles. Flowing over a bed of deposits from which it takes up additional sediment when the current is too rapid, it thus deepens the bed, and with it the slope, and thus the current declines. If it be too sluggish, deposits fall to the bottom and by raising the bed it increases the slope, and as this is steepened the current is accelerated until the normal velocity is again attained. It follows, therefore, that it is not in the power of man to *permanently* increase its current above the normal velocity. If it be increased from any cause, the water will take up an additional burden from the bed of the river, and thus enlarge and deepen its channel, and its slope will be thereby reduced, and with this reduction will follow a reduction of current, and the scouring will cease as the current diminishes until the normal rate is attained, and then the channel will be sufficiently enlarged and the slope so lowered as to prevent any further scouring.

The importance of the levees as a means of improving the navigation of the river comes wholly from the relation which the volume of a sedimentary stream bears to the frictional resistance of the bed. If the volume be diminished, the ratio of friction to the volume will be increased; and, conversely, if the volume be increased, the ratio of frictional resistance will be decreased. Hence, if it can be shown

that a higher velocity of current results from the retention of the whole volume within the levees, it must follow that a greater amount of sediment will be transported, and if this amount be greater than that which the tributaries contribute, it must be taken up out of the bed to the benefit of navigation, and the flood line must consequently be lowered to such a degree as will finally reduce the excess of current which the increased volume has produced, down to the normal velocity. The increase of volume which will be secured by the closure of these gaps will produce this increased current.

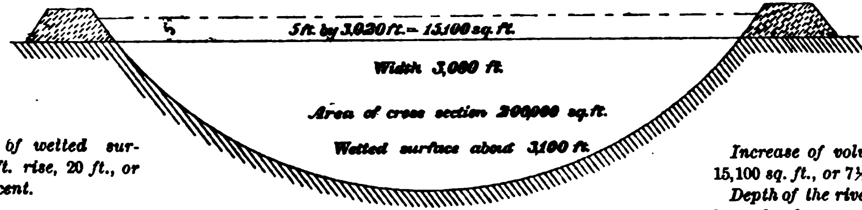
Through these a large part of the volume of the floods now escapes, and this force the river is expending in its prehistoric occupation of land-building—a process wholly incompatible with the occupation of this vast alluvial district by man. Instead of letting this worse than wasted force be thus employed, the plan recommended by the Commission proposes to utilize the entire force of the river to deepen its channel for the safe transit of the immense products of the valley, and for the safe discharge of its entire volume of flood waters without interrupting in any manner the avocations of commerce and agriculture. That it is entirely practicable to retain within the present levees the entire flood discharge of the river, if they be repaired, even without raising them any higher, I will now endeavor to prove.

The relation which the volume bears to the frictional resistance will be readily understood by examining the following diagram. Let us suppose the Mississippi River in flood to be 118 feet deep and 3,000 feet wide, and that an additional rise of 5 feet then occurs. The increase of friction in this case is only on the two sides of the channel which are in contact with this additional five feet of depth. This frictional or wetted surface on the two banks would probably not exceed an aggregate width of 20 feet. The water flowing in the stream before this addition was made to it had a frictional surface of about 3,100 feet in width. The five feet additional rise increases the cross-section in such case from about 200,000 to 215,100 square feet, or 7½ per cent., while the friction will have been only increased about two-thirds of 1 per cent.

We see, therefore, that the ratio of friction decreases with an increase of volume, and, as a natural result of this, we must have an increase of velocity of current, and, consequently, an increased capacity of discharge in the stream. But, in addition to the increase of velocity from the diminished friction, the five feet elevation materially increases the slope also, and thus adds another cause to increase the current. Carrollton is 120 miles from the Gulf; therefore a five feet rise there increases the slope half an inch per mile.

The semi-circular diagrams are intended to show how rapidly the frictional resistance increases if the river be divided into two or more channels. The large semi-circle may be supposed to represent the bed of the main river, its capacity being equal to that of the two

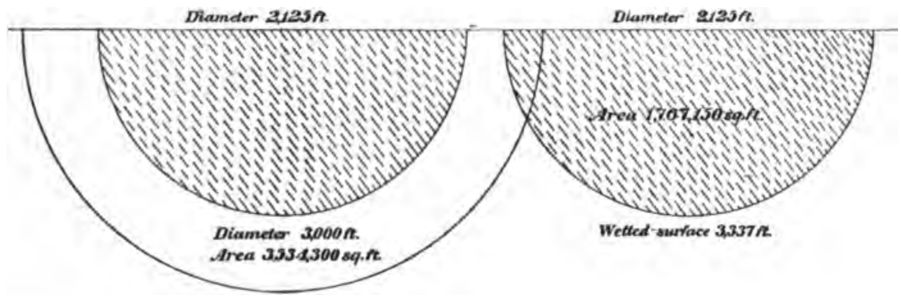
APPROXIMATE SECTION OF THE MISSISSIPPI AT CARROLLTON.



Increase of wetted surface by a 5 ft. rise, 20 ft., or ⅔ of 1 per cent.

Increase of volume by a 5 foot rise, 15,100 sq. ft., or 7½ per cent.

Depth of the river about 120 ft. at the lower level.



Wetted surface 4,712 ft.

Wetted surface of the two smaller circles 6674 ft., or 41 per cent. more than the one large circle.

Aggregate area of the two small circles only equal to that of the large one.

smaller ones. The wetted surface or frictional resistance is increased by this subdivision 41 per cent. Hence it is simply impossible for the water to flow as fast in two channels, unless they have steeper slopes, as it would if all flowed in one channel. This part of the diagram, however, is more particularly intended to illustrate the force of what I have to say later in reference to the closure of the Atchafalaya.

Some idea of the immense increase in the capacity of the river to discharge its floods, as a result of this reduction of friction and increase of slope, may be inferred from a few facts I have tabulated from the exact measurements of Humphreys and Abbot during the floods of 1851 and 1858. They are excerpted from Appendix D of their report. These measurements were made at two places on the river nearly 1,000 miles apart, and when the floods were confined within the levees.

FIRST—AT COLUMBUS, TWENTY MILES BELOW CAIRO.

1858.	Height, in feet.	Discharge per second, in cubic feet.	Mean Velocity, in feet.
June 15, 1858, height of river above low water	40 1	1,349,400	8.19
June 28, 1858	38.	1,156,960	7.22
Difference	2.1	192,440	.97

SECOND—AT COLUMBUS.

June 15, 1858	40 1	1,349,400	8.19
July 1, 1858	33.3	841,487	5.62
Difference	6.8	507,913	2.57

THIRD—AT CARROLLTON, NEAR NEW ORLEANS.

February 24, 1851	11.8	894,491	5.04
March 17, 1851	14 8	1,152,504	6.22
Difference	3.0	258,013	1.18

FOURTH—AT CARROLLTON.

1858.	Height, in feet.	Discharge per second, in cubic feet.	Mean Velocity, in feet.
February 21, 1851	10 1	766,497	4.41
March 8, 1851	14.1	1,068,464	5.81
Difference	4.0	301,967	1.40

FIFTH—AT CARROLLTON.

March 19, 1851	14.9	1,149,398	6.19
August 25, 1851	8.1	572,388	3.38
Difference	6.8	577,010	2.81

We see by the first table that when the river at Columbus was 38 feet above low-water mark, an additional rise of only 2.1 feet was sufficient to increase the mean current nearly one foot per second, and that the discharge was one-sixth greater. The depth of river at the time was about 96 feet. Therefore this 16 per cent. increase of discharge was attained with the addition of only one-fortieth part of its depth.

The second table shows that a decrease of 6.8 feet in the height of the river at this place resulted in a loss of more than 2½ feet per second in the current, and a diminution of 508,000 cubic feet per second in the discharge. If we suppose the banks of the river to have been 90 feet above the bottom of the channel, this table proves that with levees only 7 feet high upon them they would retain a sufficiently increased volume to add 60 per cent. to the discharge of the river, and over 45 per cent. to the velocity of the current.

The third table shows that at Carrollton, near New Orleans, an increase of 3 feet in the height of the river added nearly 30 per cent. to the amount which was discharged (almost doubling the percentage of increase shown with a rise of 2.1 feet at Columbus), while the current was accelerated at the same time more than 20 per cent.

The fourth table shows that at four feet greater height of the river it discharged 40 per cent. more water, and that its current was increased 32 per cent.

The fifth table shows that with a difference of only 6.8 feet the discharge of the river at Carrollton was more than double. The

river here at the lowest stage was 115 feet deep. Hence there was an increase of only one-seventeenth part of its total depth required to produce this astonishing difference in the discharge of the river. The velocity was at the same time increased 85 per cent.

These tables are the result of actual observation and careful measurements. They represent stubborn facts, without any theorizing, and they show how absurd are some of the statements made as to the effect of outlets in lowering the floods of the river. For instance, the fifth table shows that when the river (March 19, 1851) was nearly up to the highest water-mark known at Carrollton, it would have required an outlet larger than the Mississippi itself to lower it 6.8 feet. Such outlet would have had to discharge 577,000 cubic feet per second, while the whole river could only discharge 572,000 feet, when its surface was 6.8 feet lower. This enormous quantity of water (577,000 cubic feet per second) would cover a square mile one foot deep in about 48 seconds. In 24 hour hours it would cover 1,800 miles to the same depth, and in less than a fortnight it would put an average depth of three feet over an area as large as the entire State of New Jersey. To lower the river only two feet at Carrollton when in flood would require an outlet as big as Red River. This is because such loss of volume lowers the slope and increases the frictional resistance in the main stream below the outlet; and this causes it to flow more slowly, and thus prevents that great reduction in its height which the thoughtless would expect.

When we refer to the three principles governing this problem, and know how thoroughly they are established by experience, observation, and experiment, and remember the intimate relation existing between the *quantity* of sediment carried and the *velocity* of the current, it would seem impossible to arrive at any other conclusion than that the loss of velocity which invariably accompanies a lower height of the flood line can not fail to result in a deposition of sediment in the channel of the river, where such loss of velocity occurs during a flood, when the water is carrying such an enormous volume of sediment. But this fact does not rely for proof upon the plain deductions to be drawn from a consideration of the three principles we have referred to. The numerous soundings and examinations made of the bed of the river show that below every outlet its channel is reduced in size by the deposits thrown down as a result of the loss of volume through such outlet, and the consequent reduction in velocity of current.

The floods do not come so suddenly but that the increased velocity due to the increased volume is felt many days before the floods rise near the top of the levees, and if these gaps were closed I have no doubt that the increased velocity resulting therefrom would enable the floods to be discharged without any danger of their overtopping the present levees. It is possible that some very extraordinary flood,

if it occurred the next year after they were closed, might break through them or escape at some one of the lowest points in them; but extraordinary floods are exceptional, and it is altogether possible that before another one comes the channel of the river would be restored to the dimensions which it had when these levees were intact, and when they were capable of discharging any one of the ordinary floods which occurred.

If they be left open, new shoals and injurious changes in the channel will be occurring at other points of the river than those selected by the Commission for immediate improvement, and these new obstructions and changes in the channel will require much more additional work, and this will undoubtedly cost twice or thrice as much as it will to repair the levees. By repairing them the channel will not only be prevented from becoming worse at any point on the river, but the shoaling which has occurred as a result of these outlets will be removed by the effect of the levees, and the works of improvement can then be limited to the reduction of the excessively wide places which now exist, and which are enclosed by the present lines of levees. These wide places are the cause of cut-offs, caving banks, shifting channels and vexatious shoals.

The plan of improvement recommended by the Commission differs from any other previously proposed for the correction of the channel, in the fact that it looks to a rectification of the *high-water channel*, by the ultimate narrowing of these wide places, as the *only* method by which a deep and uniform low-water channel can be permanently secured.

The wide places in the high-water channel created alternations of current velocity, and steeper slopes to overcome the excessive frictional resistance. These cause the water to be highly charged with sediment at one part of its journey to the sea, and much less highly charged at others. This creates scouring and depositing in the bed, and radical changes in the channel by the caving away of its banks. By reducing these wide places to a width approximately the same as that of the narrow parts of the river, the friction is reduced, a lower slope and more uniform depth will be obtained, and the velocity of current will not be subject to its present changes. A uniform charge of sediment will result from uniformity of current velocity, and the caving of the banks will then be practically arrested, for the reason that when the water has the full charge of sediment due to its velocity it can carry no more, and cannot, therefore, scour the channel more deeply, by which the undermining of the banks is effected. Permanence of channel will not, therefore, be secured until these excessive widths are reduced. A less depth at low water than 20 feet will not insure stability of channel, for the reason that a less depth will result from only a partial reduction of the wide places. *Permanence* of channel will be attained only in proportion as uniformity of width of the

high-water channel is attained, and when this is secured the depth at low water may be considerably more than 20 feet, but it will certainly not be less. The sooner these wide places are corrected, the less will the improvement of the river cost. The maintenance of the levees, as far as they may be necessary to control the floods, will greatly lessen the cost of the work, because the retention of the water within them will prevent new shoals from forming during the narrowing of the wide places, and because the larger is the volume of a silt-bearing river *in flood time* the deeper will be its channel. Through the three hundred and thirty miles below the mouth of Red River, the river has a comparatively uniform width, and the caving of the banks is very slight as compared with the changes occurring in the eight hundred and twenty miles above Red River. In conclusion I may say that what I have urged here in regard to the closing of these gaps is but a repetition of an argument made by me before the Committee on Commerce of the House six years ago. In closing my address to the committee, I then said:

"There can be no doubt of the entire feasibility of so correcting the Mississippi river from Cairo to the Gulf that a channel depth of 20 feet during the low-water seasons can be permanently secured throughout its entire course, and that the alluvial lands on each side of its waters can be made absolutely safe from overflow without levees by such correction. This can be accomplished for a sum entirely within the ability of the Government, and one really insignificant when compared with the magnitude of the benefits which would flow from such improvement. *Until such work is accomplished an annual expenditure for the maintenance of the levees is imperative.*"

THE ATCHAFALAYA.

I cannot agree with the recommendations of the Commission for the correction of the river, at the mouth of Red River. The report sets forth the following facts:

"The enlargement of the Atchafalaya has steadily progressed since the removal of the raft therefrom by the State of Louisiana. Now it has a capacity of discharge nearly equal to Red River, and affords a line of least resistance for the flow of that stream to the sea. The discharge of Red River into the Mississippi is now small and infrequent. The outlet from the Mississippi to the Atchafalaya is almost constant, and at times very large. The elevation of the water surface at the junction of Old River, and the Mississippi (that is, the old mouth of the Red River), is almost constantly above that at the head of the Atchafalaya. The difference on the 13th of last October being 7.3 feet in the distance of about five miles. There is a marked tendency to increase this difference of level, and also to enlarge both the communication between the Mississippi and the Atchafalaya, and the Atchafalaya itself."

The recommendations of the Commission to which I object are as follows:

"We therefore recommend that at the earliest possible time a continuous brush sill be laid across Old River, between Turnbull's Island and the Mississippi, at such point as surveys show to be advisable, with the object of checking the enlargement of the outlet from the Mississippi at that point.

"We also recommend that the study of the subject be continued, in order to ascertain, first, the expediency of completing the divorce between the Mississippi on the one hand and the Red and Atchafalaya on the other."

It seems to me that these recommendations completely ignore the principles underlying the general plan of improvement recommended by the Commission. In its report, dated 17th February, 1880, these principles, in their relation to islands, are thus set forth:

"It is a well established law of hydraulics that the ratio of frictional resistance, per unit of volume, increases if the sectional area be diminished. Thus if the volume of a river were suddenly divided by an island into two channels, the water flowing in them would encounter more frictional resistance than it met with while flowing in a single channel. Hence, the currents through these channels would be more sluggish, and as the water is charged with sediment, the sluggish current would cause a deposit in the channel, which would first begin at their upper ends, and would continue until the bottoms of the two channels would be so steepened, that the current would attain a velocity capable of carrying the suspended sediment through them without further deposit, and the slope of the river's surface in in flood time, would be found to be steeper through them than above and below where the volume flows in a single channel."

When the Atchafalaya was made, it formed an island, which is bounded by the Atchafalaya, the Mississippi and the Gulf of Mexico, and it conforms precisely to the conditions set forth in the above extract. The report just referred to further says:

"In case of a crevasse, an island is also formed, having the main body of the river on the one side and the crevasse channel on the other side. As the volume flowing in the main channel below a crevasse has been decreased by the amount drawn off through it, a steeper slope in the main river, if the crevasse be kept permanently open, becomes inevitable, because the shoal below the outlet, as it grows in length down stream, from the deposition of successive floods, gradually increases the frictional resistance of the volume flowing through that diminished channel, and this tends to check the current of the river *above* the crevasse, and thus the shoaling of the river bed and the raising of the flood-line above the site of the outlet ensues as a secondary and permanent effect.

"It is in this way that silt-bearing streams, flowing through alluvial deposits, have the ability to increase or steepen their surface slopes, and thus recover the velocity of their currents, and adjust them to the work of transporting the sedimentary matter with which the flood waters are charged, so that this matter may be carried without loss or gain.

"In proof of the correctness of these views, and of their full accordance with well-established hydraulic laws, we have the evidence of this relation between slope and volume presented in the phenomena of silt-bearing streams all over the world. Whenever such

streams flow through alluvial deposits, other conditions being the same, the slope is least when the volume is greatest, and, conversely, the slope is found to be invariably increased as the volume is diminished."

There are no truths in science more capable of complete demonstration or more generally recognized by hydraulic engineers than these, and *the effects* already created by the Atchafalaya, and which are contained in the present report bear ample testimony to the soundness of the deductions thus advanced. For instance, the volume in the main river below the Atchafalaya outlet, is decreased by the volume carried off through the Atchafalaya; therefore, in proportion, as the lower Mississippi has lost this volume, according to the principles laid down by the commission, the slope of the river or its flood line should be steepened, for the Commission correctly says:

"The slope is found to be invariably increased as the volume is diminished."

The last report of the Commission says:

"No decrease of flood heights on the Mississippi, from which volume has been abstracted, is observable as the result of increased outlet, in the gauge records at Natchez, Red River, or Baton Rouge, although it practically amounts to the diversion of a tributary, with about one-sixth of the flood discharge of the Mississippi."

In other words, the Mississippi, below the Atchafalaya, is to-day carrying one sixth less than it did formerly; and, yet, no diminution in its flood line is observable at these points below the outlet. No better evidence could possibly be given of the fact that the bed of the main river below the Atchafalaya, has gradually been filled with so much deposit under the influence of the depleting effects of the Atchafalaya, that only five-sixths of the former flood volume is all that is now required to bring the surface of the floods to the same height on the levees, that they attained when the main river received the volume of the Red River.

The report states further:

"But such a decrease of flood elevation has been observed in the the Atchafalaya, to which the volume abstracted from the Mississippi has been added."

When we refer to the principles adopted by the Commission we find it stated—

"Whenever such streams flow through alluvial deposits, other conditions being the same, the slope is least when the volume is greatest."

The volume has been steadily increasing in the Atchafalaya, and, as a natural result of such increase, its slope has diminished. It now carries off the volume of the Red River and a portion of the Missis-

sippi water, and the Commission state as a fact that "a decrease of flood elevation has been observed in the Atchafalaya."

This is precisely in accordance with the principles adopted by the Commission, and these facts conclusively prove the expediency of "completing the divorce between the Mississippi, on the one hand, and the Red and Atchafalaya Rivers on the other." There is no need of further study, it seems to me, upon the question of such divorce; but, on the contrary, there is every reason for *immediate action* to prevent not only the further loss of volume from the Mississippi, but to restore to it the discharge of Red River, which is now going down the Atchafalaya. It would probably not be advisable to reduce the cross-section of the Atchafalaya to restrain more than about one-sixth of its volume, per annum, which would thus occupy six years in its complete closure; although the tables I have already given of the discharge of the river at Columbus and Carrollton show that the entire discharge of the Red, if added to the Mississippi when both are in flood, would only increase the height of the Mississippi two feet below the Red River. The steepening of the slope of the Mississippi below the Atchafalaya has been progressing ever since that outlet began to be enlarged, and, as an immense amount of deposit must have fallen on the bed of the stream to raise the bottom of the river so high that the abstraction of one-sixth of its original volume produces no reduction in the height of its floods, the removal of this deposit should be made gradually. If it be permitted to rob the Mississippi of this great tributary permanently, by the construction of the proposed sill, we may be certain that a further raising of the flood line of the Mississippi will be the consequence, not simply *below this outlet, but above* it also. Of course, if the capacity of the crevasse be increased, as in this instance, additional shoaling will occur in the bed below it. It is not easy to foretell exactly how long the secondary effect (that of shoaling *above* the outlet) will continue. The diminution in the capacity of the channel below the outlet increases the frictional resistance, because *the ratio* of friction increases as the volume is diminished. But *the amount* of this additional resistance increases as the shoaling extends on down stream, for the same reason that a long pipe of a given capacity and slope will not discharge as much water in a given unit of time as a shorter one with the same head, diameter and slope. Hence, although the channel is diminished by deposits immediately below an outlet during the next ensuing flood, yet this shoaling may not extend sufficiently far down stream to react perceptibly upon the current *above* the crevasse, until after successive floods have still further extended the shoaling and thus lengthened, as it were, the diminished channel through which the river then flows. The raising of the flood-line *above* the outlet, by which an increased slope is given to the river *below it*, is, however, only a question of time, if the outlet remain in full force. It

will gradually raise the floods higher and higher above the outlet, until a steeper slope below it restores the normal current. The slope of a sediment-bearing stream is adjusted by laws as immutable as those which control the planets, and a further flood elevation above this outlet, if the volume of the Red River be lost to the Mississippi, is inevitable. To me it seems that no treatment of the river is more plainly indicated by the observed facts than that which I have the honor to recommend upon this subject. I have not the least doubt in my own mind that the complete closure of the Atchafalaya will produce a lowering of the flood line, at the mouth of the Red River of several feet, within a few years afterwards. The prevention of the escape of any portion of the discharge of the Red River down the Atchafalaya, will also have the effect of benefiting the navigation at the mouth of Red River; it will restore deep navigation between the Red and the Mississippi River, without the necessity of further works. Communication between the Atchafalaya and Mississippi, by a system of locks, will become a necessity before the complete closure of that outlet, but these would also be still more needed if the Red and Atchafalaya be separated from the Mississippi, as the commerce of the Red River must then be provided for also. The lowering of the slope, which will certainly follow the closure of this outlet and the reunion of the Red and Mississippi, will benefit the river channel and lower the floods so materially throughout the entire 820 miles of river between Commerce and Red River, that the saving in the cost of maintenance of the levees during the correction of this part of the river, will enormously exceed the cost of the works, including the locks for the Atchafalaya; besides, it will give to the extensive region between the Red River and Commerce much more complete immunity from overflow, by the enlargement of the Mississippi River below the Atchafalaya; while the Atchafalaya country will be made safer and safer in proportion as the head of that stream is closed.

Instead of constructing the sill to interrupt communication between the Mississippi and the Atchafalaya, I would, for the reasons given, earnestly recommend the immediate construction of a sill in the Atchafalaya, near its upper end, to diminish the volume flowing through that outlet; and, from year to year, as rapidly as may be deemed safe, cause this sill to be built up until it shall finally constitute a dam, completely separating the Atchafalaya from all communication with the Red and Mississippi Rivers. The result of this will be to increase the volume flowing in the main river, and improve the depth of water on the bars below the Red River, on which, at low water only ten feet depth now exists.

HARBOR OF VICKSBURG.

The report recommends that the improvement of this harbor be attempted by revetting Delta Point against further erosion, and by dredging out a basin and a channel leading to the harbor, by which steamers will have access to Vicksburg landing. The first cost of this dredging is estimated at $336,000, and the revetment of Delta Point at $100,000 more. I do not believe Delta Point can be permanently revetted for an additional $100,000. Two hundred and twenty-nine thousand dollars have been heretofore appropriated for this purpose, and, as the report declares, this work, "owing to many unforseen difficulties, has been much more costly than was anticipated." The failure to successfully revet and maintain this point will increase the estimated cost of dredging the channel and basin proposed in the report.

My experience has taught me that of all methods of deepening channels in, or connected with the Mississippi river, that of dredging is one of the most costly, uncertain, and least permanent. The plan proposed if carried out *successfully*, would entail upon the Government *an annual expenditure* for the dredging of this basin and canal, which would, no doubt equal one-eighth and, and most likely one-sixth of its first cost, or at least $40,000 per annum. This would represent the interest on at least a million dollars, and with the first cost of the work would make this plan of improvement cost about a million and a half dollars. For this sum and perhaps for much less, the river can be made to resume the channel it followed thirty or forty years ago, when it washed the shore of Vicksburg, and before it created the extensive bend now cut off by the new channel, at the foot of which bend the city of Vicksburg stands. I should not attempt to restore the channel around De Soto Island, but simply extend Delta point until a sufficient portion of the island is cut away to force the channel against the wharf. This method of improvement would make the river flow in a permanent channel at Vicksburg, and save its citizens from the uncertainty which would attend the maintenance of a channel and harbor by dredging, and from the certain injury to the commerce of that city and to that of a large district dependent upon it for the conveniences of shipment, in the event of congress failing at any time hereafter to make the regular annual appropriation which would be required for dredging out the proposed channel and basin. I do not believe the plan recommended will be attended with satisfactory results if it be executed.

For these reasons, and because I know it is practicable to extend Delta Point artificially to a sufficient distance to throw the channel against the old landing at Vicksburg, I recommend that this work

be undertaken for the permanent rectification of the river at this place. Approximate estimates made by me show that this can be accomplished for $1,200,000, and deep water permanently secured at the Vicksburg wharf without further outlay for maintenance. Two hundred and fifty thousand dollars could be profitably expended upon this work during the ensuing year.

IMPROVEMENTS BETWEEN THE MOUTHS OF THE MISSOURI AND OHIO RIVERS.

The Commission, in its report, in speaking of the improvements now being carried on by the War Department, between the mouths of the Missouri and Ohio Rivers, a distance of about two hundred miles, says:

"The success of Captain Ernst's works thus far justifies, in our opinion, the methods he has employed, and we are of the opinion that it should be pushed toward completion under liberal appropriations."

I cannot join with the Commission in this endorsement and recommendation, for the reason that the plans now being executed by Captain Ernst have never been submitted to me for examination. I have been informed that a committee, appointed by the Commission, did examine these plans and approve them; but so far as I know they were never submitted to the Commission itself.

Before I would feel justified in giving my approval to detail plans for the improvement of any portion of the river, it would be necessary for me to carefully consider them, not merely in the light of the immediate results which the works might be expected to accomplish, but also as to their effects upon other parts of the river. It would also be necessary to know whether the plans proposed for the special locality were in full accord with the general plan of improvement recommended by the Commission, and, assuming the plans to be correct, whether they were to be carried out with due regard to economy in the expenditure of money.

Under the act of Congress creating the Commission, it is charged with the responsibility of reporting plans for the improvement of the entire river, and it alone is responsible for them. I do not believe the public expectation will be met by exempting so extensive and important a section of the river as this two hundred miles from the supervision of the Commission. This was done by a clause in the last appropriation of $600,000 for this part of the river, and the effect of the present recommendation is to encourage the disbursement of a like sum without any control of the works by the Commission.

I do not desire to be understood as condemning the plans which are now being executed by Capt. Ernst; but I cannot unite with the Commission in endorsing them, for the reasons stated.

Very respectfully,

JAS. B. EADS.

WASHINGTON, D. C., April 12th, 1882.

ADDRESS

AT A BANQUET GIVEN TO GENERAL U. S. GRANT, EX-PRESIDENT OF THE UNITED STATES, AT NEW ORLEANS, APRIL 5, 1880.

Mr. President and Gentlemen:

I frankly confess that I love the praise of those whom I respect, and that I swallow down flattery and kind words with more relish than I do good wine, and of that I take all that my judgment and my physician declare to be safe for me to appropriate. In fact, praise is pleasant, even when one's own heart tells him it is undeserved. But with all my love of it, I am not vain enough to appropriate to myself a tithe of the cordial greeting which the mention of my name and the praise of my over-partial friend has called forth. For I know that it belongs to a number of statesmen, capitalists, editors, and men whose wisdom, money, influence, intelligence and labor, united under God's grace, and through the application of his immutable laws, to secure a deep channel at the mouth of this mighty river, for the hitherto pent-up commerce of the grandest empire on the face of this globe. As the executive officer of that noble commonwealth, I thank you for this cordial recognition of the value of the service it has rendered to our common country and to mankind. For wherever the peaceful keels of commerce are driven by wind or steam, no matter how distant the shore, or how strange the language that may be there spoken by our fellow-man, some benefit, flowing from the enfranchisement of the commerce of this valley, will be felt by him.

The jetties were commenced under the administration of our distinguished guest. The law which authorized their construction bears the autograph of Ulysses S. Grant. From the first inception of the

enterprise, the man whom all the nations of the world have so recently, so unprecedentedly, and so justly honored, was its earnest and faithful friend. And I am justly proud of the fact that he was and is the friend of him to whom the Congrees of the United States entrusted the direction and execution of the work.

Now let us pause for a moment to contemplate in the presence of him who sanctioned the jetty act, what that work has already accomplished. For but few men, as a distinguished Senator recently said to me, realize what has been saved to the country by the opening of the mouth of the Mississippi.

I am told by some of the most intelligent and experienced merchants in St. Louis that transportation to Liverpool has been cheapened at least 5 cents per bushel on grain by it, almost all of which saving inures to the producers. This apparently small sum becomes so enormous when multiplied by the totals of the cereals of the valley that I cannot credit the statement, for the saving is not alone on that which passes out through the deep channel of the jetties. When, after the Northern winter is over, the cheap water transit of the Erie canal is available, the rates of every competing railway are reduced, and the producer feels its beneficial influence even though his grain may go by the railway. And so it is with the railways which compete with the Mississippi river. Hence this saving, whatever it is, is made also on the products which go from the valley across the mountains to the sea. But the saving does not stop here, for it is an axiom that the grain which remains upon the farm, and which is fed to the cattle and hogs, or is otherwise consumed, has its value fixed by that which is sold in the market. We see, therefore, that deep water at the mouth of the river by this saving in the cost of transportation, has raised the value of the produce that goes through the jetties, and the value of that which seeks the competing railways, and that which enters into home consumption. That is, it has raised the value of the entire products of that part of the Mississippi valley which is naturally tributary to its great water system.

Let us see what this means. The corn crop alone of the six great grain-growing States for the past year is estimated at one thousand million bushels. If its value has really been raised five cents per bushel, the increase is equal to $50,000,000 in one year, or enough to pay half the interest on the public debt.

In conclusion, gentlemen, permit me to say that I believe every reflecting lover of his country, both North and South, must view with pleasure the generous and cordial reception which our distinguished guest has met in New Orleans. To me it seems the dawning of a better era. Until the past is forgiven (if not forgotten) on both sides, the full prosperity of the South cannot be assured. It is human for each to think his cross is the heaviest one that is borne, and hence the vanquished are prone to forget the lasting wounds they dealt

those who would now, though still smarting from them, be good friends. Let the dead past go, and look only to the future. Put your hand to the plow and don't look back. Let us unite to develope the magnificent heritage which God has given to us. Through the richest and grandest part of it He has caused a mighty stream and its majestic tributaries to flow in one whole and complete system, thus combining diversified immensity of wealth into harmonious unity, and teaching us to cultivate a brotherhood of feeling and a homogeneity of interest.

In ancient and fabled lore we learn that forgetfulness of the past was symbolized by the waters of a stream called Lethe; but here we have a grander lesson taught by our own great river. Whether its waters are born among the snows and ice of the jeweled sides of the Rocky Mountains, or on the distant water-shed of the North, or burst from the warm bosom of the earth in crystal springs upon the sunny slopes of the Apalachain chain, they will flow alike in quiet harmony through the same channel and to the same bourne, and their waves seem to murmur as they pass—"Let us have peace; let us have peace."

LETTER

To Joseph Medill, Editor and Publisher of the Chicago Tribune.

Mr. Joseph Medill.

Sir,—In your paper of the 8th instant you published a series of misstatements under the offensive title of "Eads' Enormous Lobby."

The statement that I have a lobby here is absolutely untrue. No one except myself and my private counsel, Hon. A. G. Cochran, who has attended to my law business for the last three years, is, or has ever been authorized to speak to a member of the United States Senate or House of Representatives in behalf of the ship railway bill.

I quote the following from your article:

"Capt. Eads himself is the most audacious, unprincipled, and successful lobbyist the national capital has ever known. He is now in receipt of a half million dollars annually paid him for maintaining a channel of thirty feet 'through the jetties' at the mouth of the Mis-

sissippi, though it is notorious that the depth of water at the head of the South Pass is less than twenty-five feet, probably not more than twenty-three feet."

He who is most ready to suspect wrong in others is generally least pure himself, but in your case this slander has the additional incentive arising from an innate love of misrepresentation and abuse. For years your paper has been the channel through which my private character has been grossly assailed and my professional labors belittled and misrepresented. You well know (for you were one of my most unscrupulous opposers) that the House of Representatives in 1874 passed a bill appropriating $8,000,000 to begin the construction of the Fort St. Philip canal, and that I saved the Government from this blunder by undertaking, at my own risk and cost, to deepen the South Pass bar to 30 feet, for five and a quarter million dollars. A reference to the report of the Secretary of War for 1874 and 1875, vol 2, part 1, page 866, will show that the estimated cost of the canal was thirteen million dollars. It is safe to say that this canal would not have been completed in fifteen years, and that it would not have cost less than twenty million dollars. I defeated the canal by agreeing to construct the jetties, the largest national improvement yet authorized, on the severest terms the Government ever imposed. I offered to secure twenty feet through them before the Government was to pay anything whatever. The act of Congress accepting this proposition was passed in the House by an overwhelming vote, and with but little opposition in the Senate, yet you would make your readers believe that Congressmen are so corrupt that such a proposition required "audacious and unprincipled lobbying." You know, and the intelligent public will remember, that as I asked no relief from the great pecuniary burdens imposed upon me by the terms of the act, until the channel had been deepened from eight feet to twenty-two feet, and the commerce of the Mississippi River had been relieved from a thralldom which every effort of the Government during thirty-seven years had been powerless to overcome. The next two acts of Congress (and the only ones I have ever had anything to do with) were likewise passed by overwhelming majorities in both houses. One of these acts authorized the payment to me of $1,000,000, and the other, three-quarters of a million more; both sums being in advance of the terms of the original act, but the total compensation being in no wise increased. The passage of these two amendatory acts was a most conspicuous mark of the confidence which Congress had in me, and a substantial acknowledgment of my perfect good faith towards the Government. Through the wisdom of Congress and the confidence of capitalists, I succeeded in saving to the Government at least seven and three-quarter million dollars, being the difference between the cost of the jetties and the estimated cost of the canal.

Tne commerce of the valley was at the same time relieved at least ten years sooner than would have been possible by the canal. The success of the jetties has resulted in reducing the rates of transportation on all the produce of the vast region tributary to the river, whether they take the jetty route to market or not. This saving to the producer is not less than $22,000,000 annually, and probably much more.

While I was devoting myself to the labor of accomplishing this great result, encouraged by a generous public sentiment, and an enlightened press, you were publishing every indecent assault that a few disappointed and malicious persons could devise. You busied yourself in predicting and frequently announcing the utter failure of the jetties, and filled your columns with absurd theories in regard to the phenomena of the river, conceived in ignorance, and advocated with the sole purpose of preventing the successful consummation of the work at the jetties. You signally failed to accomplish your purpose, but have not ceased to publish the most untruthful statements concerning the jetty channel.

The declaration that I am receiving half a million dollars annually for maintaining 30 feet of water through the jetties is a gross misstatement. I receive only one hundred thousand dollars per annum for it, and last year I expended nearly that entire amount upon the jetty works. You characterize this as a "shameful and indefensible bargain." The jetty act expressly provides that whenever the United States shall elect to undertake the maintenance of the channel it can do so at once to stop the payment to me of this annual amount. Your statement therefore is a "shameful and indefensible" untruth.

Your declaration that the depth of water at the head of the pass is less than twenty feet is also untrue. Through the jetties, and at the head of the pass, the depth is nowhere less than thirty feet. The limiting depth is in the pass itself, which I am not required by law to maintain; it is, however at least twenty-seven or twenty-eight feet. The fact that vessels of greater draft than twenty-five and a half feet have not yet gone through the jetties is largely due to the untrue statements continually published about the channel in your paper and in one or two others equally unreliable.

I again quote from your article as follows:

> "The dinner ostensibly given by Stilson Hutchins of the Washington *Post* to the entire newspaper press represented at the capital is commonly understood to have been paid for by Capt. Eads."

I knew nothing about Mr. Hutchins' dinner until I had the honor of an invition to it. To assert that I paid any part of the cost of it, directly or indirectly, is untrue. It was an elegant affair and as it was given in honor of the press, your attempt to disparage it makes the homely adage of "the dirty bird" peculiarly applicable to you.

Again you say:

"The dinner given to the retiring minister from Mexico by ex-Senator Hipple Mitchell of Oregon may not have been an entertainment of the same character, but Eads was a conspicuous orator there also, and had several influential senators and representatives among his auditors."

This statement is also untrue: I was not at the dinner party given by the honorable ex-senator from Oregon, and hence could not have been a "conspicuous orator there also."

Your oft repeated slanders and abuse concerning me during the last few years have marked you as one devoid of every sentiment of truth and honor. Without further comment, I leave you to enjoy as best you may, the public contempt which your conduct merits.

JAS. B. EADS.

WASHINGTON, March 19, 1882.

LETTER

TO THE EDITOR OF THE ST. LOUIS REPUBLICAN RELATIVE TO THE SOUTH PASS JETTIES.

ST. LOUIS, December 17, 1882.

Editor Republican:

You state in this morning's *Republican* that I am not required by law to maintain a depth of 30 feet through the jetty channel. This is a mistake. I am required to do so, and have done so for more than three years.

The clause in the amendment to the jetty act, by which my obligation to maintain the jetty channel, approved March 3, 1879, are defined, is as follows:

"The one hundred thousand dollars per annum provided by said recited act to be paid to said Eads and his associates during a period of twenty years, shall be paid at the time and in the manner therein provided, upon the maintenance by said Eads and his associates of a channel through the jetties twenty-six feet in depth, not less than two hundred feet in width at the bottom, and having through it a central depth of thirty feet, without regard to width."

The jetty channel is about two and a quarter miles long and is at

the mouth of the South Pass. It is almost wholly in the Gulf of Mexico. The pass itself is ten miles long and is from six to eight hundred feet wide. In it the depth varies at two or three places according to the stage of the Mississippi River, but it is rarely, if ever, less than 26 feet. Frequently the least depth in it is from 28 to 30 feet. At the head of the pass a shoal in the Mississippi obstructs the entrance into the pass. Through the works built to deepen this shoal there is never less than thirty-five feet.

There has been no time during the three years that I have been paid for maintaining the channel through the jetties that a vessel drawing 30 feet could not have passed in or out through them. None have gone through, however, drawing more than the Quebec, viz: Twenty-six feet and two inches. The depth in the pass being less than that which I am required to maintain in the jetties, has furnished a pretext to the enemies of the improvement to declare that the depth required by the law has not been maintained.

The amendment of 1879, just quoted, was intended to limit my obligation to maintain the channel to the jetties alone, for the reason that I am not paid for maintaining the channel through the pass.

The Commission of 1875, on whose advice Congress finally acted, declared that the South Pass was "entirely adequate to the present and future wants of commerce." I did not think so, but strove to have the Southwest Pass bar improved, as the Southwest Pass is double the width and depth of the other. The Commission estimated the cost of the works at the head of the South Pass and at its mouth at $5,342,110. I undertook it for five and a quarter millions. It estimated the cost of maintaining the jetties at $139,000 per annum, contemplating a channel of only 25 feet depth at low tide, and I undertook for $100,000 to maintain them and to guarantee a channel 3¾ feet deeper: that is, a thirty-foot channel at high tide.

The Commission's estimate for *construction* included the reduction of the shoal at the head of the pass, and I reduced it. Its estimate for *maintenance* included no work in the pass, for its capacity was deemed adequate; and it included no estimate for the maintenance of the channel at the head of the pass, rightly assuming that that channel, once secured, would remain permanent. It no doubt assumed also, and correctly, that the size of the pass would be maintained intact without work, because the full volume then flowing in it could not be reduced if the jetty channel be maintained at its maximum capacity. These facts were fully considered by the committees charged with the subject, and it was upon their advice that Congress in 1879 clearly limited my obligations to the maintenance of the specified channel "through the jetties."

As the enemies of the improvement of the Mississippi are continually misrepresenting the facts connected with the construction of the

jetties, I would respectfully suggest that this letter be retained for future reference, as it contains facts which would otherwise require the examination of several official documents not always available to combine and present them in convenient form.

JAMES B. EADS.

LETTER

LAID BEFORE THE LEVEE CONVENTION AT BATON ROUGE, JUNE 18, 1883, BY THE GOVERNOR OF LOUISIANA.

ST. LOUIS, May 31, 1883.

His Excellency Samuel D. McEnery, Governor of Louisiana:

DEAR SIR,—I am honored by your invitation to attend the convention called by you at Baton Rouge, to consider the subjects of crevasses, levees and the improvement of the navigation of the Mississippi river. I regret that I shall not be able to be present, as I sail on the 20th of June for England, on business of the Tehuantepec ship railway.

Having in the last ten years had frequent occasion to discuss publicly the river problems, in defence of my plans and works for the improvement of its mouth, as well as in support of my views for the rectification of the channel of the river, and the protection of its alluvial lands, my opinions are so well known and recorded that my presence in the convention could not be of any special benefit.

Consequences of vast magnitude may be largely influenced by the action of the convention. I have an abiding faith that prudence and wisdom will characterize the conclusions of the gentlemen who will compose it.

I think that the convention should not lose sight of the facts—

1st. That the improvement contemplated by Congress, has reference solely to THE NAVIGATION OF THE RIVER, and not to the protection of its alluvial lands; and

2nd. That this improvement is one in which the whole nation is deeply interested, and whose consummation is favored by a great majority of its citizens. Hence, any effort to influence the action of Congress in favor of any local interest, by which the general system of improvement adopted by that body is modified or in any way interfered with, will, I think, be utterly futile.

Fortunately for the owners of alluvial lands, the safety of their property will be inevitably assured by the correction of the river's channel. The desired low water channel cannot possibly be secured except by bringing the high water channel to a comparative uniformity of width, and when this is accomplished, the levees will be useless and inundations practically unknown. This rectification of the river can be more readily accomplished, and for much less money, by maintaining the present levees in repair during the progress of the work. The only argument for keeping them in repair is the fact that the retention of the increased volume within the channel of the river by a perfect levee system will give deeper channels for navigation in low water, and will prevent changes in the channel from occurring at localities which do not now need rectification, thereby saving much cost in the work of improvement.

To recommend to Congress that any important lateral outlet be kept open—the Atchafalaya, for instance—or to recommend the deflection of any important tributary from the main river—the Red River, for instance—is not only a direct violation of the principles adopted by the Mississippi River Commission as the basis of the plan of improvement which Congress has sanctioned by millions already appropriated, but it weakens, if it does not totally destroy, any claim based upon channel improvement, which the riparian States can advance in favor of the maintenance of the present levees by the general government, until the completion of the improvement of the channel. Such a recommendation on the part of the convention would, I believe, be as unwise as it is unnecessary. It could only be urged upon the sober attention of the convention by a total misapprehension on the part of interested individuals. The Atchfalaya can be closed and the flow of the Red River restored to the Mississippi so gradually that there can be no possibility of any harm occurring to the lands supposed to be endangered thereby.

If the Mississippi lose the volume of Red River, its channel will not only be injured, but its flood surface will be raised. Only a small majority in Congress favors the maintenance of the levees intact at Federal expense, because it believes in the fact that the betterment of the channel will be more quickly and economically attained thereby. Is it not asking too much of these friends of the levees, for the sake of some purely imaginary advantage to a small area in Louisiana, to make a notable exception in the general plan of channel improvements already adopted, that will not only increase the cost of levee maintenance, but actually lessen the benefits sought to be secured for navigation?

I have the honor to be, with great esteem,

Your obedient servant,

JAS. B. EADS.

REPORT

On the Mouth of St. Johns River, Florida.

Jacksonville, Fla., March 29, 1878.

Hon. W. Stokes Boyd, Mayor, and Mr. Thos. A. Wilson, President of the Citizens' Meeting, Jacksonville:

Gentlemen,— In compliance with the request of the city council and of the citizens of Jacksonville, conveyed to me through your letter of the 26th of February, 1878, to examine and report upon the practicability of deepening the channel through the bar at the mouth of the St. Johns River, I have the honor to submit the following

REPORT.

A personal examination of the mouth of the St. Johns River, and a study of the official surveys of the bar and river, together with such other reliable data in connection therewith as I have been able to obtain, confirm the following facts:

The territory drained by the St. Johns River comprises an area of about 7,500 square miles. The average rain-fall upon this area during the last twenty-seven years equals 50.27 inches at Jacksonville, and about sixty inches over the more southern portions of this area.

The mean tidal oscillations at Fort George's inlet, near the mouth of the river, are five feet and four-tenths; the highest observed tide being seven feet and one-tenth above the plane of reference, and the lowest one foot and two-tenths below that plane; the extreme range being eight feet and three-tenths.

The oscillations at Pilot Town, within the mouth of the river, and distant about three statute miles from the outer edge of the bar, are nearly one foot less. At Jacksonville, the mean rise of the tide is but nine-tenths of a foot. The river is quite tortuous, the distance between the Jacksonville wharf and Pilot Town being fourteen statute miles in a direct line, while by the line of deepest water or river channel, it is twenty-four miles. The width of the river at low water immediately above Pilot Town, is about 1,740 feet, and its greatest depth at mean low tide at this point, is thirty-six feet, its sectional area here at low water being about 36,000 square feet.

This is the narrowest part of the river below Jacksonville. At Jacksonville, it is about 2,000 feet wide, with a maximum depth of twelve fathoms. Its greatest widths between these towns, are at Dunn's Creek and Mill Cove, ten and thirteen miles respectively below Jacksonville. At the first place it is 2.2, and at the last, 2.8 miles wide.

The average width of the river, between Jacksonville and Pilot Town, is one mile. A mile below Pilot Town the shores of the river gradually widen out to the sea. The southern bank, a bluff one, twenty-five or thirty feet high, trends off east southeast, or nearly at right angles to its direction opposite Pilot Town, while the northern shore, a low, marshy one, bends around to north-northeast, which general direction it follows for about a mile, when it trends quickly around to the north, its low, compact sandy beach receiving the full force of the waves of the Atlantic for a mile beyond, at which distance the shore-line is interrupted by Fort George Inlet.

About two miles and a half by the shore-line of the river, above Pilot Town, Sister Creek or Inlet enters the St. Johns on the north side, and by a tortuous channel about 400 feet wide, having a general direction to the north, connects the Nassau and Amelia Rivers with the St. Johns, and furnishes an inland navigation to Fernandina for vessels of five or six feet draught during flood tide.

About midway between the St. Johns and Nassau Rivers, the Fort George Inlet connects the Sister Inlet with the Atlantic Ocean, and separates Fort George Island from Talbot Island. Both Talbot and Fort George Islands are subdivided by a small inlet running north and south, by which another inland connection is made between the St. Johns, Fort George Inlet, and Nassau River. This last-named inlet, through Fort George Island, is called Haulover Creek.

The width of the river's discharge, measured along the outer two fathom contour of the bar crest, and at right angles to the outflowing current, is nearly three miles.

The shoals which occupy the fan-shaped area inclosed between this contour line and the expanding banks of the river constitutes the St. Johns bar, and cover an area nearly three square miles in extent.

An inspection of the different surveys of the bar, and information derived from several intelligent and experienced pilots, confirm the belief that the deepest channels which have existed through the bar, have occupied, at various times, almost every part of this extensive area.

At present the river struggles to reach the sea through three well defined channels. One of these, called on the charts the Pelican Channel, lies nearly in the direction of the axis of the river volume where it leaves the plainly defined shores of the stream. This channel extends eastwardly between two large and prominent shoals, both of which are dry at half tide; one of these is called North Shoal, and the other Pelican Reef. South of Pelican Reef, a still deeper channel

is found, which follows the south shore so closely and so far around, that the St. Johns River light is finally hidden by the shore from the view of a vessel passing out through it, and then the channel suddenly bends to the east and enters the ocean. This is called the South Channel, and at present it is the deepest one, having at mean high tide about ten feet on it. Before the light house is lost from view when in it, this channel throws off a branch to the east, called the Middle Channel, through which nine feet can be carried at high tide.

The material forming the bar is essentially the same which forms the sand beaches to the north of the river's mouth, the bottom through the various channels on the bar being compact, and so firm as to endanger the hulls of vessels crossing it in heavy seas by thumping the bottom of the channel. Those unfamiliar with the subject would infer from its firmness that it would yield but slowly to the action of the current, whereas no material is more sensitive to any disturbance of the equilibrium of forces which caused it to come to rest, than the sand composing such bars.

An examination of the meteorological records of the United States Signal Service for the past five years, for which I am indebted to Mr. Gosewich, in charge of the office here, shows that the prevailing winds are from the northeast. The mean of the five years being 7.2 months during which the wind was from the north or northeast. We may therefore reasonably infer that the prevailing littoral, or shore current of the sea, flows southward in front of the river's mouth during the same period of time.

The height and protrusion of the southern bank of the river into the sea, would indicate the presence of a current to the south during most of the year, for the general tendency of all silt or sediment bearing streams entering the sea at right angles to prevailing sea currents, is to have their mouths turned around towards such currents as though opposing them.

This is because the sedimentary matters discharged by the stream are carried by sea currents across the mouth of the stream and deposited on the shore beyond. The constant accumulation of earthy matters on that side causes that bank to grow more rapidly out into the sea than the other, and as these matters continue to accumulate upon it, the course of the river is gradually forced around by the deposits on that bank into a direction apparently in antagonism with the sea current.

During the greater part of the remaining four months and a fraction, it is quite likely that the sea current runs in the opposite direction, or to the north, as the wind is, during those months, chiefly from the southeast or south.

As the St. Johns carries but little sediment to the sea, the bar, at its mouth, is of the kind known as drift bars, a term used to distinguish them from those formed by alluvions or river deposits, at the

mouth of delta rivers, such as the Mississippi, the Danube, the Dwina, the Rhone, etc.

Over the profounder depths of the ocean, the water constituting the waves simply rises and falls vertically, like the material of a carpet when spread out horizontally, and shaken by men standing around it. The waves move horizontally, one after the other, but little or no horizontal motion of the water occurs as a result of the progress of the waves alone.

But the case is quite different when the water in its vertical decent feels the resistance of the sloping bottom of the shore. A horizontal motion in the water is then produced, slight at first, where the shore is deep, but increasing as the depth diminishes, and always moving shoreward. As the waves increase in height the horizontal motion becomes so swift in depths of from one to three fathoms that the water of the advancing wave-crest rushes rapidly forward and falls over the water in the trough before it, and thus forms what are termed breakers.

Observations of tidal waves have established the fact that the velocity of such waves is greatly influenced by the depths over which they pass. In fifty fathoms the velocity is about sixty miles per hour, while in 5,000 fathoms it is about 528 miles. The waves produced by the winds are similarly affected by depth. Their velocity is, consequently, arrested as they approach the shore. Those nearest the beach are overtaken by those which follow, and which are in deeper water, and overwhelming, at recurring intervals, those in advance of them, increase the height of the breakers in rythmical periods.

The shoreward or horizontal motion imparted to the water is called translatory motion; and the rapidity and distance to which the ocean-swells are driven out upon its sloping beaches, illustrate its action. Consequently, wave-action in shallow depths near the coast has a constant tendency to sweep up the sands in such depths and deposit them on the shore. Under the operations of these almost incessant forces, which are heaping up the sands on the shore, and the opposing influence of gravity inclining them to run back again, the beach assumes a certain inclination or slope, which is called the angle of repose. This angle is altered when the wave-force, creating the motion of translation, is intensified by storms, and it is steeper or flatter according to the character of the material brought shoreward by the waves. Shingle and coarse sand assume steeper slopes than quicksand, which is composed of rounded particles, and that which is left above the mean range of the tide is steeper than that which is constantly submerged. The more violent are the waves, the greater will be the depths from which sand, shells, loose stones, etc., will be swept up by this motion of translation, on to the shore.

From this it is evident that every river emptying into the sea, unless

under exceptional conditions, must struggle through the sands that are thrown up shoreward by the waves. These, in reality, are continually striving to barricade the river current and prevent it from entering the sea. In the contest, the river forces, under the ever-varying intensity of hydrostatic pressures resulting from freshets and tides, are as constantly sweeping down the sandy barriers thrown up by the waves, and, seeking out the lines of least resistance, the river flows through continually shifting channels across the bar.

In this eternal warfare of opposing forces, the sands at the river's mouth are driven first in one direction and then in another; at one time by the tides, at another by the river, and again by the waves over the whole area of the bar, constantly extending it into the sea, by the accumulations of the river sediment and the ocean sands, until it is built out so far seaward that its further growth is retarded or stopped altogether, either by the currents of the sea, or by the steepness of the shore line, or by both causes combined.

It must be evident from this simple explanation, that the extent of the shoreward movement of the sands caused by wave-action, is increased by the height of the waves, and that it decreases with an increase of depth.

The sands in four or five fathoms of water are but little disturbed by wave action, except in storms, although even large stones have been moved by the waves of very violent storms in much deeper water.

If the discharge of a river in a tideless sea require a certain width and depth of channel for its accommodation, and the natural cross-section be too wide and shallow, we may safely assume that if the width be reduced by compelling the water to flow through artificial banks, such as jetties or piers, the depth will be proportionately increased in the narrowed channel between the jetties. If the volume be so great as to give a depth of twenty feet between the jetties, we may safely assume that none but storm waves will have power to move the sands on the ocean's bed in front of the channel; while the river-current, being thus concentrated, would be more potent to repel the advancing current induced by the waves and thus neutralize its effects. As storms are of brief duration, while the outflow of the river is more or less constant, it is plain that such jettied channel would maintain such depth as the volume of the river demanded, almost if not wholly irrespective of the effects of the translatory action of the waves. It must likewise be evident that the deeper the channel between the jetties, the less liable will it be to even a temporary diminution in depth from the effect of storms.

This only supposes such artificial contraction of width is made to the mouth of a river discharging in a tideless sea, and having sufficient volume of discharge to maintain a depth of twenty feet or more through a jettical channel of the requisite width.

Let us suppose that jetties be applied to the St. Johns, and assume, for the time being, that no fresh water at all is discharged by the river into the sea. We will, then, have the conditions reversed; that is, we will have no river discharge, and we will have a mean rise and fall of tide equal to five and a half feet. Leaving out of consideration the magnificent lacustrine river above Jacksonville, we find extending from Jacksonville to the sea, a river basin twenty-five miles long, and averaging one mile in width. At one end of this basin the average rise of the tide is nearly one foot, and at the other end five and a half feet. The average quantity of tidal water passing into and out of this basin twice a day, is therefore equal to nearly 2,000,000,000 cubic feet. This would produce an average rate of current equal to two miles per hour, through a channel having a cross section of 30,000 square feet, or a maximum current during average flood and ebb tides of about four miles an hour.

With such a tidal basin, *even without the additional advantage of the river current*, resulting from a large annual rain-fall upon 7,500 square miles drained by it, I should have no hesitation in recommending the application of parallel jetties at the mouth of the St. Johns river, as a certain means of permanently deepening the channel through the bar at its mouth. Every inlet into the sounds or tidal basins which border the eastern sea coast of the United States is an evidence of the ability of the ebb and flow of the tides to maintain a depth of channel from the ocean into these basins, and to resist the influence of the wave-action, which would otherwise soon shut off these basins from all connection with the sea. The depth of these channels is determined by the volume of tide water forced through them in filling and emptying the different basins into which they lead, and by the width of the inlet. If the latter be artificially contracted, the depth of the channel will be increased, and the quantity of water received and discharged by the basin will be greater because the flow of the water is retarded by the friction caused by its contact with the bed of the channel. If the channel be narrowed and deepened, the frictional surface will be lessened and the basin will fill faster. The friction that must be overcome by the water in passing in during flood tide over the great expanse of the St. Johns bar causes the tide to rise one foot less in height inside the bar at Pilot Town, than it is outside of it at Fort George Inlet. Hence, if jetties were applied to reduce the width of the inflowing waters, now nearly three miles wide, and they were caused to pass through a channel only three or four-tenths of a mile wide, the frictional resistance would be greatly decreased, and higher tidal oscillations would occur at Jacksonville. The river channel would therefore not only be deepened over the shoals in the river by a higher plane of water at high tide, but the increased flow of tidal waters through the river would deepen the bottom likewise and materially improve the navigation of the river.

The size of the river at Pilot Town, immediately above the bar, where it is exceptionally narrow, furnishes more reliable means of determining the width and depth of channel that can be maintained across the bar with the desired depth between parallel works, than any mathematical formulas, relating to the flow of water; for there are so many influences which patient experimental investigation would fail to correctly estimate, tending to modify the results of any strictly technical solution of the question, that such method would be unreliable. The bends of the river, the width of its bed, the irregularity in the flow of the tides, and the difficulty of determining the varying volume of the river's discharge, all influence the result, and all conspire to maintain the size of the channel at the point referred to. At this point we find that by the combined influence of the tides and fluvial discharge, the currents maintain a section 1.740 feet in width, with a maximum depth of thirty-six feet, the area of the section at half tide being 36,000 square feet. This maximum depth could not be secured at the sea ends of the jetties with the width found at this point, for the reason that under the influence of the waves of the ocean, the bottom of the channel there would assume a flatter shape than in the river.

The width of channel to be determined through the jetties should not only be considered with reference to commercial requirements, and to the amount of water to be discharged through it by the combined volume of the river and the tides, but also with reference to the cost of construction and maintenance of the works, for these will be more expensive in proportion as the channel is deeper, and the channel will be deeper in proportion as it is contracted by the jetties, within certain limits.

The width found at Pilot Town, say 1,700 feet, is sufficient to secure a judicious mean between the probable demands of commerce, and an economic expenditure for construction and maintenance. This width, I feel confident, will produce a reliable channel, of at least 20 feet in depth at average flood tide. The depth will more probably be twenty-three or twenty-four feet, through jetties of that width.

The most judicious location for the jetties can only be determined by a careful survey, which survey, owing to the shifting nature of the channel through the bar, should be made immediately before commencing the work. A permanent artificial channel can be made through almost any part of the bar, but the location which will produce the best results for the least expenditure, can only be determined after such survey as I have suggested. The direction of the jetty channel should be such as to furnish the longest straight line of current into the river, as the in-flow of the tide will be diminished by bends in the channel. Its discharge should be as nearly at right angles to to the littoral currents as may be practicable with the desired straightness of in-flow. On the accompanying chart I have in-

dicated such alignment of the works as I have deemed most judicious for the conditions shown by it. It is possible that a survey immediately preceding the construction of the jetties may show no important difference in the form of the bar, and in such event I would make no alteration in the location shown on the chart.

The mode of construction should be similar to that used at South Pass. Although willows cannot be conveniently obtained in the vicinity, other materials are at hand in abundance with which to construct brush mattresses for the work. Palmetto piles can likewise be abundantly obtained, and as these are not attacked by the toredo, they can be advantageously used to lessen the amount of stone that would otherwise be required.

When the construction of the works is begun, the foundation courses of mattresses for both jetties should be laid from the land to the sea end of the jetties before any portion of the work is built up to its full height. The height of the jetties should be at least two feet above mean high tide.

I have made an estimate of the total cost of the proposed works which is based upon the most reliable data I have been able to obtain. While the cost may be considerably modified by the results of subsequent surveys, and by the skill and experience of the engineer who may be charged with the execution of the works, and while the estimate is necessarily only approximate, it will be found sufficiently accurate and reliable to base legislative action upon, and sufficiently liberal to insure the execution of the work by competent persons, for the sum named. A more exact estimate can only follow a careful and thorough survey and the preparation of detail drawings. The estimate embraces the following materials in place in the works, which are necessary to complete the jetties, two feet above high tide, from each shore of the river to the fifteen-foot contour curve on the outer face of the bar. It includes fifty per cent. for settlement and contingencies. The total length of the two jetties will be three and one-half miles.

ESTIMATE.

425,000 cubic yards of mattress work, $2.25	$956,250
90,000 cubic yards of stone ballast and riprap, $6.00............	540,000
864,000 linear feet of piling, 20 cents..............................	172,800
240,000 feet board measure of lumber, $20,00.....................	48,000
	$1,717,050

The mattress foundations of the sea-ends of the jetties are 250 feet wide, and a similar width is deemed necessary in the line of the south jetty where it crosses the south channel near the main shore.

I have not deemed it necessary to make an instrumental survey of

the bar, as it would involve considerale time and expense. The surveys I have consulted are as follows:

1st. A Spanish chart by Mariano de la Rocqe, 1771.

2d. A comparative chart of surveys, by Lieutenant T. A. Craven, U. S. N., assistant 1853, and S. D. Trenchard, U. S. N., assistant United States Coast Survey, 1857.

3d. United States Coast Survey preliminary chart, 1856.

4th. Sketch of the bar, February, 1873, furnished by the United States Light House Board.

5th. Sketch of the bar, February, 1874, furnished by United States Light House Board.

6th. United States Coast Survey chart of St. Johns river, 1878.

I am much indebted to Dr. A. S. Baldwin, for valuable and pertinent information, and for the loan of several instructive charts, reports and books relating to the problem under consideration. This gentleman has given many years to the study of the subject, and has brought to the investigation of it a large amount of scientific research, aided by close observation of the phenomena presented. I give in his own brief language what he deems the chief cause of the shifting channels across the bar, and the reason of the river discharge being unable to maintain a single channel of greater depth and stability. Dr. Baldwin says:

"Owing to their proximity, difference in volume of water, and sources of supply of the respective streams, there is an interchange of water between the St. Johns River and Fort George Inlet, producing cross-currents, quite detrimental to the free and normal discharge of the waters of the river, through a direct and unshifting channel to the sea. To remedy this condition of things, the cause of abnormal action must be removed.

"The closure of Fort George Inlet, or the diversion of its waters through Haulover Creek, enlarged so as to give passage to them into the river above its bar, so as to cause a commingling of the waters of both streams inside of the bar, instead of an interchange outside, has appeared to me to promise a successful result by removing the cause of cross-currents which now interrupt navigation and interfere with the free discharge of the river over the bar.

"The momentum or force of current due to its large volume will enable the river to open and maintain a channel sufficient for all present or prospective wants of commerce, provided this water can be kept in a concentrated stream, and my opinion has been, that if the deflecting influences of the inlet could be removed, the stream then would not be so liable as now to be divided into numerous channels; but the waters would then be disposed to concentrate into one stream, having sufficient power to sweep out of its pathway all obstructions to its free passage to the sea, without assistance from artificial appliances to either side of the channel, because I have attributed to the cross-current or see-sawing motion of waters across the north shoals, between the river and inlet at different times of tide, a prominent part, and the principal instrumentality in shifting the banks of sand and preventing the river from having any permanent and well defined channel."

The deep water, in front of the beach, seen on United States Coast Survey charts, between the mouth of the river and the inlet, shows the existence of such an interchange of waters as Dr. Baldwin refers to, as a result of the difference in time of the tide action in the inlet and the river, and I think it is quite possible that some improvement of the bar-channel might have resulted from the carrying out of his suggestions, but not sufficient to meet the wants of commerce. It is, however, very evident that a line of works nearly one and three-quarter miles long transverse to such currents as may be due to the cause assigned, would completely interrupt them and prevent their evil effects.

In addition to the plan of improvement recommended by Dr. Baldwin, Lieutenant, (now General) H. G. Wright, United States Engineer, recommended, in 1853, the construction of a single pier on the north side of the channel. The length and proposed location of this pier I have no information about. Single piers have been applied to drift bars in tidal and non-tidal waters with benefit, but the superior advantage of protecting the channel by parallel piers or jetties has been so abundantly demonstrated within the last twenty-five years as to leave no question about the propriety of applying them in this case. They have been applied at the mouths of many rivers on the Baltic and the European coast, and on the upper lakes, with marked success. The engineers who oppose the jetty system of improvement at the present day, I believe, have confined their objections to its use entirely to delta forming rivers, and have based their predictions of its failure at the South Pass, on the fact that the Mississippi discharges an immense amount of sedimentary matter, which they asserted would cause a rapid reformation of the bar, immediately in advance of the jetties. This conviction on their part was strengthened by the belief that no littoral current existed there to sweep away this large discharge of sediment. They claimed that the great success of the system was due to the fact that the rivers whose bars had been deepened were comparatively free of sediment, and that the outer face of the bar was swept by a littoral current. As both these conditions exist at the St. Johns Bar, the recommendation herein made to improve it by jetties will doubtless be cordially endorsed by them, while it cannot, I am sure, fail to meet the approval of those engineers who advocated their application to the bar at the mouth of the Mississippi. Their success there has only confirmed the fact that the system is equally applicable to either delta or drift bars. The present Chief of Engineers of the United States Army declared, in 1875, in his annual report, that the jetty system had never been applied to the bar of but one delta-forming river (the Rhone), and that it had been a failure there. This has been publicly declared to be a mistake, by Colonel W. Milnor Roberts, C. E., who visited the mouth of the Rhone for the express purpose of examining

into this very question. He was accompanied by several members of the United States Commission of Engineers, who afterwards reported, in 1875, in favor of applying the system at the mouth of the Mississippi. Colonel Roberts has stated the fact, which I and other engineers, who have visited the mouth of the Rhone, well knew, namely, that the jetty system never was applied there at all. Dykes were built in the river mouth to close several latteral outlets and cause the river to discharge through one mouth only; but these dykes were never extended out into the sea, over the bar, to deep water, as is proposed for this bar, and as was done at the South Pass, at the Danube, the Dwina and the Maas—all of which are delta-forming rivers. The dykes at the Rhone were never nearer than seven-eighths of a mile from the crest of the bar.

To confound any one who who still persists in declaring that the jetty system failed at the Rhone, it is only necessary to ask him to point out among all of the many successful applications of the system, one single instance where the jetties are not built out in the sea across the bar to the deep water beyond, and then ask him to state if those at the Rhone were ever built out on to the bar at all.

As the jetties at the ship canal at Amsterdam and those at the Maas, besides innumerable others on the Atlantic, have proved their ability to withstand the severest ocean storms, it is scarcely necessary for me to advance any arguments to show that the proposed works can also be made thoroughly permanent.

The importance of improving the St. Johns Bar as a matter of national interest will scarcely be questioned, in view of the advantages it offers as a naval station on our South Atlantic coast, and as a harbor of refuge.

The delightful climate of Florida, the ease with which many semi-tropical and remunerative products are reared, such as sugar-cane and cotton, and its adaptability to the production of oranges, lemons, figs, dates, bananas, peaches and berries of the finest qualities, are rapidly attracting an industrious and energetic population. Its vast forests already furnish important shipments of lumber, tar, pitch, turpentine and rosin, and its gardens furnish to the North large quantities of vegetables, melons, etc.

Notwithstanding the immense disadvantage of the bar at the mouth of the St. Johns, the shipments of lumber, in 1877, from Jacksonville, amounted to 40,000,000 feet, on which a freight was paid $1 per 1,000 higher than on that shipped from Brunswick and Fernandina. In this one item alone it will be seen that the bar has cost $40,000 per annum in extra freights. The vessels leaving port are frequently detained for days, and even weeks at the bar, waiting for favorable tides and deeper water, at a large aggregate cost for demurrage. This is estimated by intelligent and well informed parties

to cost the commerce of the St. Johns not less than $100,000 additional per annum.

In consequence of the delays at the bar the clearances at the custom-house, at Jacksonville, have steadily declined from 80,798 tons in 1873, to 39,681 tons in 1877.

The river tonage consists of thirty steamers, navigating about 400 miles of the St. Johns river and its branches.

For these interesting statistics I am indebted to Mr. M. W. Drew, of Jacksonville.

I am likewise under obligations to the owners and officers of the steamers Hampton, Gazelle, Mary Draper, Sappho, and tow-boat R. L. Mabey, for their courtesy in enabling me to examine the river and bar during the past week on these steamers. My thanks are alse due to the proprietors of the Carleton house and Fort George Hotel for hospitalities extended to me during my stay in Jacksonville and at the bar.

I have the honor to be, very truly, &c.,

JAMES B. EADS.

Respectfully submitted, with a Chart of the St. Johns Bar.

REPORT

UPON THE HARBOR OF TORONTO.

Hon. Sir H. L. Langevin, C. B., K. C. G. M., Minister of Public Works, Canada:

SIR,—I have the honor to submit the following report upon the Harbor of Toronto.

Before making a personal inspection of the harbor, I expressed the wish that I should be furnished with such information relating to it as would be useful in a study of the questions upon which my advice was desired. In response to this request I have received a compilation of the available records touching the harbor, entitled "Memorandum with accompanying plans and documents relating to the past and present state of the Harbor of Toronto." At the same time I received the following letter:

"No. 6532, July 13.

"DEPARTMENT OF PUBLIC WORKS, CANADA,
Ottawa, 19th April, 1881.

"SIR,—The preparation of the information you desired to have relative to the Harbor of Toronto prior to the examination you are to make, having been completed, I now inclose the same in pamphlet form, and am directed by the Honorable the Minister to request you to proceed with such examination at your earliest convenience.

"There are two points which will demand your serious consideration:

"1st. The western entrance,—its proper width and depth, and the means to be adopted to maintain both, as well as to restrain or prevent the growth of the island shoal northwardly and westwardly, either by works erected at the entrance or from the island, or both.

"2d. The eastern entrance,—whether it is desirable that it should remain open; if so, the means to be adopted for its maintenance to an ample width and to a depth equal to that of the western entrance. If it should be closed, the manner in which this should be accomplished and its future maintenance provided for.

"You will be kind enough to report fully on these points, as well as on all others having a bearing on the preservation or improvement of the harbor which may be brought to your notice during your examination, such reports to be accompanied by plans and estimates of the cost, and such suggestions as you may be pleased to make.

"Although your attention is called to certain points for investigation, it is the wish of the Minister that your report shall be full and comprehensive, and embrace everything which may have a bearing on the object of your inquiry.

"You will please notify the Chief Engineer when you propose visiting Toronto.

"I have the honor to be, sir, your obedient servant,

(Signed) "F. H. ENNIS, Secretary."

The Memorandum and its appendices contain a mass of important information upon the subject in hand, which will be found very useful in forming a correct judgment as to the merits of any system of works which has been or which may be suggested for the benefit of the harbor. But as the careful examination of these facts *in extenso* may be inconvenient when this report is under consideration, and as they constitute a part of the evidence by which I have been guided, I think it proper to append to this report a copy of the Memorandum, as it contains in a compact form the gist of the information which is embodied in the entire volume.

During the latter part of last June I visited the city of Toronto and met the Chief Engineer, Henry F. Perley, Esq., there by appointment. Through his courtesy I was provided with every facility necessary to enable me to make such an inspection of the harbor and its vicinity as I desired. During my examination I was accompanied by the Chief Engineer, and by Mr. Kivas Tully, Engineer of the Harbor, and from these gentlemen I obtained, verbally, much useful information. Mr. Tully's knowledge of the harbor is the result of many years of close and intelligent observation of its phenomena,

while residing in Toronto. During my visit I made as thorough an inspection of the harbor as I desired, and fully informed myself as to the causes which in my opinion have produced its deterioration.

As no instrumental survey of the harbor had been made since 1879, and as an accurate knowledge of the most recent changes in it was important, not only in arriving at a correct solution of the problem, but also in making an accurate estimate of the cost of the works needed for its improvement, I requested that another survey should be made with especial reference to the changes which had occurred in its two entrances, where works of improvement would probably be located. This survey the Chief Engineer caused to be made during last July and August, and I have been furnished with the results. I am therefore in possession of all of the information requisite for an intelligent and thorough study of the subject. This study I have made, and I trust that I shall succeed in presenting to the Dominion Government, in as convincing a light as they are presented to my own mind, the several reasons that have induced me to make the recommendations herewith submitted. To aid me in this part of my task I desire to impress on the memory of the reader each one of the three facts presently named, which appear to me to be the most important phenomena in the consideration of the very novel problem presented by the Harbor of Toronto.

First. There has been for nearly a century a constant growth of the northern end of the peninsula in the direction of the Queen's Wharf.

Second. Although this extension has diminished the *width* and *depth* through the entrance or throat of the harbor, it has not materially altered the *distance* which existed sixty-three years ago between the deep water immediately inside the harbor and that near the entrance on the outside of it.

Third. While the crest of the extremity of the peninsula has advanced about 1,700 feet to the west in the last sixty-three years, its submerged face on that side has greatly receded, and the deep water of the lake along its western shore has proportionately moved to the east, thereby resulting in a much steeper slope on this side of the peninsula, to the depth of at least 18 feet, than it had in 1818.

These three facts are so important that the proof of each one in order is herewith submitted.

In proof of the *first*, we learn that in 1788 Mr. I. Collins, Deputy Surveyor General, reported the navigable channel for vessels to be 1,500 feet wide and from 18 to 20 feet deep. The waters of the lake at the time were, as he says, very high. The survey of Bouchette, five years later, shows only 15 feet as the maximum depth and a channel 480 yards wide. Much of this difference in the maximum depth and width and that reported by Collins was doubtless due to the different level to which Bouchette referred his measurements.

In the very interesting and instructive competitive report of Mr. Sandford Fleming, C. E. (page 64 of the appendix to Memorandum) we find the following statement:

"On comparing the charts of Bouchette, Bayfield and Bonnycastle, with my own from a recent survey [in 1850], showing the state of the peninsula at the present time, we obtain results as follows:

"First. That the channel between ten (10) feet water lines was, in—

"1796, about 480 yards wide;
"1828, about 310 yards wide;
"1835, about 260 yards wide;
"1850, about 120 yards wide."

This comparison is entitled to much confidence, for the reason that it was evidently made by a careful and intelligent engineer, who had within reach at Toronto at that time, the necessary data to determine the difference in the lake levels to which these several surveys were referred, and without which information no accurate comparison of these surveys could have been made.

From these comparisons, and from his estimates, Mr. Fleming arrived at the conclusion, that the northward growth of the peninsula reduced the width of the channel at the rate of from seven to ten yards annually, and that this required a deposit of about 11,000 cubic yards each year. The annual growth during the years embraced by his comparison is shown to be remarkably constant and regular.

On the 11th of April of this year, as appears by the chart of comparative surveys from 1875 to 1879, inclusive, the width between the Queen's wharf and the ten-foot contour line on the peninsula was only about 225 feet, and much of this width is, no doubt, due to dredging.

The *second* fact is shown by a comparison of Mr. Fleming's survey of 1850 with the most recent one made this year. The 15-feet inside and outside contour-lines on the latest survey measured across the end of the peninsula where they approached each other most nearly, are about 2,400 feet apart.

In comparing the latest contours with the 15-feet contours of Mr. Fleming, it should be observed that there are two 15-feet soundings on his chart in the bight of the outer curve which are not embraced by it. If the curve were drawn through the outer one of these, which it might be with equal propriety, the line would be moved out about 420 feet. The distance would then be about 2,200 feet between the two 15-feet contours on Mr. Fleming's chart, if measured over the line of least distance between the same contours on the survey of 1881. This line crosses the end of the peninsula about 1,350 feet from the end of the Queen's wharf. On a line nearer to the Queen's wharf the distance between them on Mr. Fleming's chart is only about 1,800

feet. The lesser distances between these contours on Mr. Fleming's survey are owing to the higher datum plane from which the depths were measured. He says (page 69, Memorandum and Appendix), that his report was "chiefly founded on a very laborious and expensive survey between August, 1849, and the spring of 1850." With regard to the datum level, he says:

"These soundings amount to between two and three thousand, and are reduced to an approximate mean level of Lake Ontario, ascertained in conjunction with Captain Lefroy from a series of lake levels taken by his direction during several years."

This level is, I believe, about one foot and a half higher than the present datum established by the late Captain Hugh Richardson in 1850. The hydrographic diagram of Mr. Kivas Tully shows the mean level of the lake during twenty-five years ending in 1879 to have been 18.20 inches above the present datum plane.

No material difference is observable between the last survey and that made by Mr. Fleming thirty years ago, in the width of the shoal between the 15-feet contours at the locality named, when the discrepancies I have alluded to are duly considered. That this distance has not appreciably altered in the last six years admits of no question, when the survey of 1875 is compared with that of 1881.

In still further proof it is proper to quote the following from the report of Mr. William Kingsford, engineer in charge, dated July 7th, 1875, who seems to have been a close observer of the changes in the harbor and its entrances. He says (page 110, Memorandum and Appendix): "The eastern spit of land which protects the harbor is formed of sand, much of which is frequently in motion. It has been asserted that, carried away from the original place of deposit, it finds its way into the harbor. The examination of last year proves that such is not the case. There is no less depth of water to-day in the inner harbor than is shown on the map of the first survey made by Bouchette in 1785 "

The proof of the *third fact* referred to, will appear by making the following comparison of Bayfield's survey with the survey of 1881. Draw a line upon each from the light-house to the centre of the Queen's wharf, and from points on this line measure, perpendicularly to it, the distances to the 2, 4, 10, 15 and 18 feet soundings shown on Bayfield's chart near the central part of the western face of the peninsula, and compare those depths with the depths at the same places on the chart of 1881.

First. At a point on the line 4,500 feet from the light-house we find it is about 1,900 feet to the most southerly one of the two feet soundings. At this place, on the survey of 1881, the depth is now thirteen feet greater.

Second. At a point on the line 5,600 feet from the light-house it is

1,500 feet to the next two feet sounding on the Bayfield chart. At this place the depth is now six feet greater.*

Third. At a point on the line on the Bayfield Survey 4,000 feet from the light-house, it is 1,400 feet to the southern four-feet sounding. The depth here is now 2.7 feet greater.

Fourth. At a point on the line 4,300 feet from the light-house, it is 1,200 feet to the other four-feet sounding. The depth at this place is now one and a half feet greater.

Fifth. At a point 4,750 feet from the light-house it is 2,000 feet to the ten-feet sounding on Bayfield's chart. At this place the depth is now nine feet greater. The ten-feet contour here has receded 400 feet.

Sixth. At a point on the line 5,000 feet from the light-house it is 2,000 feet to the fifteen-feet sounding of Captain Bayfield. At the same place the present depth is four feet greater. The fifteen feet contour has receded here about 200 feet.

Seventh. At a point on the line 5,200 from the light-house it is 2,050 feet to the eighteen-feet sounding on Bayfield's chart. The present depth here is about two feet greater.

These comparisons are sufficient to show that the five-feet contour line about the middle of the western face of the peninsula is at very nearly the same place now that it was sixty-three years ago, while the contours between 5 feet and 18 feet have greatly receded.

A further comparison of Captain Bayfield's Survey with that of 1881, will prove by similar measurements that the dry crest of the northern end of the peninsula has not only advanced to the north, but has likewise advanced to the westward about 1,700 feet from the end of the sand spit shown on Captain Bayfield's chart, by which the western face of the peninsula above the five-feet contour line has been much steepened by a movement precisely the converse of that which has steepened it below that depth. The sand which constituted the bottom beyond the present five feet contour line in 1818 out to the depth of eighteen feet, has evidently been transported by the action of the waves up to the northward and on to that part of the western face of the peninsula which is now above the present five-feet contour. This process has greatly steepened the western face of the peninsula without really advancing it lakeward.

If comparisons be made further southward on the face of the peninsula, the change wrought by wave action in this direction will be still more marked. For instance, at a point on the line from the Queen's wharf to the light-house, 2,600 feet from the latter, the Bay-

* NOTE.—This latter two feet sounding and others on the same shoal are shown more distinctly on an engraved chart of Bayfield's survey published "with corrections" in 1863. They are scarcely discernible on the photo-lithograph published with the Memorandum.

field chart shows a depth of but three feet on the outer face of the shoal at the distance of 2,600 feet. The depth here must now be about 19 feet, as the spot is about 100 feet outside of the outermost sounding on the chart of 1881, where a depth of 18.5 feet is recorded. The depth of three feet is now 1,600 feet eastward on the survey of 1881. If we assume that the plane to which Captain Bayfield reduced his soundings was eighteen inches higher than the present datum, it would still show that the three-feet contour at this locality is 1,550 feet further landward than it was in 1818.

From this and other comparisons which may be made between these two surveys, it will appear that while the top or dry part of the peninsula at its northern end has apparently swung out towards the lake about 1,700 feet westwardly, the submerged portion of it, at the southern end of this face, has, to the depth of eighteen feet, swung in towards the light-house about the same distance eastwardly. The common centre about which these changes seem to have vibrated from east to west, is located near the central portion of the western face of the peninsula. The centre about which the vertical movement has occurred by which the entire face of the peninsula has been steepened, seems to have been at the depth of about five feet, and at a point also near the central part of the western face of the peninsula. In this movement the eighteen-feet contour at the northern end has not materially changed its location, while the zero margin of the lake at the other end, immediately west of the light-house, has been almost if not quite as stable.

The prolongation of the isthmus northwardly and the alteration of its western face, are unquestionably due to wave action, and as a proper understanding of the phenomena produced by waves is absolutety necessary to enable the reader to form an intelligent judgment of the merits of the conclusions arrived at, in regard to the causes of the changes which have occurred at the harbor of Toronto, and of the probable results of the remedial works herein proposed, I will be pardoned for explaining the manner in which the waves affect the sand and other materials composing the bottom of seas, lakes, etc.

A simple illustration of the action of waves on the surface of *very deep water* can be made by tightly stretching a long cord between two points and then striking it near one end. The wave produced by the blow travels rapidly back and forth along the cord from end to end, but the material of which the cord is made, simply rises and falls without advancing with the wave. So it is with the *water* where the lake is deep. The wave may pass ever so rapidly, but it cannot of itself set up any continuous horizontal motion in the water. A bird or a buoy afloat upon it would simply rise and fall as the waves passed under it. At the same time it would have a slight motion to and fro in the direction the waves are traveling, but unless impelled by the wind or a current in the lake, it would remain in the same locality.

The case is quite different, however, when the wave reaches water so shoal that the bottom resists the sinking of its crest. When this resistance is felt, the water which at that moment constitutes the wave, has, as a result of this resistance and of its own momentum, a horizontal motion imparted to it. This horizontal impulse becomes still greater as the depth lessens. Hence, although the velocity of the wave itself is diminished as it reaches shoaler depths, the water through which it passes has a constantly increasing velocity imparted to it in the direction of the shore, and in the case of big waves it becomes so swift that it is driven with great force out upon the beach.

This translatory motion gives to the waves the power to take up from the sea bottom, or to set in motion, the sands, shells, and other materials of which it is composed, and to transport them shoreward with more or less force. The quantities thus transported depend upon the size of the waves, the formation of the shore upon which they exert their force, and the size, gravity and abundance of the material acted upon.

The direction of these translatory currents is determined by the shape of the sea bottom. If the shore be precipitous, very little or no such current will be created; but where the bottom is sloping to the sea, the waves will be constantly directed shoreward, no matter how obliquely they may approach it. Hence, waves on such shores are continually piling up reefs and beaches, and through some of these every river must struggle to reach the sea, unless it enter it between bold headlands, and is incapable of transporting enough detritus to form a delta at its mouth; or unless some sea current exist sufficiently strong to sweep away the sedimentary matter brought down by it. Of course the height of the wave determines the depth at which the resistance of the bottom is felt, and at which the horizontal motion of the water is first induced. The depth will therefore be the extreme limit at which the material of the bottom can be set in motion by the wave. A study of the surveys which have been made on the western shore of the isthmus at Toronto satisfies me that the waves which roll in upon it are not large enough to move the sand when the water is over 18 feet deep. I can discover no evidence that the bottom has been disturbed at a greater depth there during sixty-three years; and the area within which the waves are formed that break upon it, forbids the belief that they are large enough to affect the bottom at a greater depth. The magnitude of a wave does not depend so much upon the force of the wind, as upon the "fetch" or distance through which it can travel without interruption, and the depth of the water on which it moves.

Waves travel much more rapidly in deep than in shallow water. This is the cause of the phenomenon called "breakers." As each wave approaches still shallower water, its speed becomes still more

retarded; hence the wave behind is alway moving more rapidly than the one in advance. As it gains upon its predecessor it gets the benefit of the deeper water of that wave. The result of this is that at regularly recurring intervals or rythmic periods, one of the waves completely overtakes the one in front of it, by which it secures for itself a still greater depth and maintains the velocity due to that depth. This enables it to travel so rapidly over the one it has surmounted, that it outstrips it in the race, and consequently falls over in front of it, or, as it is termed, "breaks."

The wave has more ability to carry the sand up on to the beach than it has to bring it down again notwithstanding the slope of the shore. This is because the ratio of frictional resistance of the shore increases as the depth of the water passing over it is diminished, and also because the material carried up on to the beach, is almost wholly suspended in the water. The interval of time required for the shoreward current to come to rest and for the return current to be started, is sufficient to permit the sand to fall to the shore, from which the less rapid current seaward is unable to remove it.

A very important part of the study of our problem is involved in the inquiry as to whether the portion of the isthmus now constituting an island is undergoing any serious alteration in its size. Is it being added to? Or is it diminishing? We know that its form has been altered to the serious injury of the channel, by the extension of the peninsula northward. It is a matter of great importance to know whether the material which has been added to the end of the peninsula in the last 63 years has been brought from Humber Bay, Scarborough Heights or elsewhere, or whether it has been transported from the southwestern portion of the peninsula itself.

If it has been brought from the eastern shore of the Lake, from Humber Bay or Niagara, we must look for an annual contribution of the same kind indefinitely, from such foreign source, and this fact would thrust into any plan for the improvement of the western entrance, a very embarrassing element. This material would accumulate about the entrance of our works, to such an extent as to need annual dredging and probably an extension of the necessary piers from time to time. With such a prospect I should not hesitate to advise that the western entrance be abandoned and that the remedial treatment, although much more expensive, be at once applied to the eastern gap. It is, however, only necessary to make an approximate estimate of the amount of material which has been removed from the western face of the peninsula, near Gibraltar Point, northward, and within a distance of about 2,000 feet westward from its present margin, to know that the immense quantity of sand which covered the lake bottom over this area in 1818, and which has how been removed by wave action, was quite sufficient to have transferred the crest of the peninsula 1,700 feet westward in the shallow depths then existing, and to

have added to its length all of the material which it has received during the last 63 years, without any contributions from foreign sources.

I have made some approximate estimates of the quantity of sand which has been removed from this area during the last sixty-three years. On the large chart accompanying this report, which is a copy of the survey made by Mr. F. M. Hamel in 1881, will be found a line drawn from the light-house to the Queen's wharf, with four lines at right angles to it. These are designated as "A. B." "C. D." "E. F." and "G. H." In comparing the sections, as nearly as possible with those similarly located on Baysfield's chart, I find that south of line "A. B." in the last 63 years there have been removed about six million cubic feet. Between lines "A. B." and "C. D." sixteen million, two hundred and fifty feet. Between "C. D." and "E. F." eighteen millions, seven hundred and fifty feet. Between "E. F." and "G. H." five million, one hundred thousand feet, and north of line "G. H." one million, four hundred thousand cubic feet, making in all, forty-seven million, five hundred thousand cubic feet; or, one million, seven hundred and sixty thousand cubic yards. This is at the rate of about twenty-eight thousand cubic yards per annum; an amount amply sufficient to account for the northward growth of the Peninsula and likewise for the westward advance of the crest of it. The data are not sufficient to enable me to determine what amount of it has been deposited to the eastward of the line between the Queen's wharf and the Light-house, but it is evident from the foregoing that no addition from any foreign source has been made to the northern end or western face of the Peninsula since Bayfield's survey. The changes which have occurred on the western face of it, give substantial assurance of the permanency of the western entrance to the Harbor, if it be located in accordance with the recommendations hereinafter made.

No grain of sand rests upon any part of the shores of the peninsula, or in the channel, that was not brought to its present resting place by a current of water which left it there because it was not able to move it farther. The slope of the shore is therefore the result of an equilibrium between the force of the currents which sweep over it, and of the opposing force of gravity in the sand. The slope which the shore assumes under these different forces is termed in technical parlance, its "angle of repose." Owing to the greater mobility of the sand when saturated, this angle is flatter or lower on the submerged part of the shore than on the dry reefs or beaches. Where a broad channel is exposed to storms and is swept by violent waves in different directions, the bottom becomes still flatter. Hence the angle of repose assumed, is so low that any natural channel through such deposits on the sea coast, must possess great width if it have any considerable depth in its central part. This will be better seen

when it is remembered that it is about 1,200 feet from the shore line on the western face of the peninsula out to 16 feet of water, although this shore is under the influence of wave action which is quite favorable for the maintenance of a steep angle of repose. A natural channel, therefore, if formed of the same materials, which I assume to be almost wholly of sand, would, if it were possible to have its opposite shores swept by similar waves, require to be 2,400 feet wide to maintain a central depth of 16 feet. In a narrow and sheltered channel the sand would maintain an angle of from four to six horizontal, to one vertical, or about eleven degrees. The perimeter of the cross-section of a channel swept only by currents moving in directions parallel to its axis, conforms very nearly to the arc of a circle.

The ability of a river to carry the detritus with which its water is charged, is due to the velocity of the current. When it reaches the sea the current subsides, and the sediment, before held in suspension, is deposited. The sea waves leach out by continual agitation the argillaceous and other lighter portions of these deposits, while the sand, gravel and heavier materials are left to dam back the river and form the foundations upon which it in turn builds up its banks still further out. Their low slopes defy the fury of the waves, and if any littoral (or shore) currents prevail in the sea where the river is thus extending its banks, this current carries the river deposits to the leeward, builds up that bank more rapidly than the other and compels the discharge finally to flow in almost direct opposition to the prevailing sea current. In this way a river will extend its banks out many miles into the sea, its direction being determined by the littoral current or by the prevailing winds. The Mississippi has thus extended its length about sixty miles out into the Gulf of Mexico beyond the present shore lines of the gulf, and its course has been almost directly *against* the direction of the prevailing winds. As the river extends itself into the sea, its banks on the mainland are continually being raised by the annual overflows. These deposit the heavier materials carried by the current close to the river, while the lighter portion, which takes longer to settle, is carried back to the swamp lands. In this way many silt-bearing streams, the Mississippi, the Rhine, and the Po, for instance, have, as they approach the sea, built up their banks many feet higher than the lands on each side of the river.

The direction which rivers take when their channels are built out in the sea is frequently such as to almost completely inclose extensive bays. After such process has been carried out to a greater or less distance in the sea, the height of the river on the main land becomes so great that a breach finally occurs in the seaward bank during some extraordinary flood, and the river then takes the shorter way through it to the sea. In such case the channel which it had constructed below the breach is abandoned. Being no longer a con-

duit for the fluvial current, it is filled up by the action of the waves, and at the same time the height of its banks is reduced to the sea level or below it, and what the river constructed finally becomes the foundation of a peninsula, on which every evidence of the fluvial channel above the surface of the sea is completely obliterated. The Vistula, Adour, and Senegal are among the numerous examples of rivers forming such new outlets to the sea, many miles above their former mouths. The long, narrow peninsulas which separate the Frisches Haff and the Curisches Haff in Eastern Prussia from the Baltic no doubt had their origin in the extensions of the Vistula and Pregel into that sea.

A peninsula thus formed, having its axis parallel to the prevailing winds, receives constant additions by wave action upon its extremity, which continues to extend it, generally, though not always, against the wind. If a constant current of the sea sweep along its side in the direction of the end of the peninsula, the accretions thrown up by the waves in storms on the side of it are gradually transported along in calmer weather toward its extremity. The side is thus kept steeper and prevented from widening, while the sands thus removed fall to the bottom again in the more sluggish current or eddy which exists at the end of the peninsula. Here an extensive shoal forms during the calmer weather, to be afterwards thrown up on it by the force of the waves. The sandy breakwaters which inclose the long series of extensive sounds on the coast of Virginia, the Carolinas, and Florida are examples of this kind of peninsula formation. The same process is carried on in tideless seas, though not in such vast extent. The Baltic, Mediterranean, Black Sea, and the Great Lakes present many examples of such phenomena.

The sea currents almost invariably carry more or less sand along the shores, and thus furnish the material for the waves to extend the peninsulas. If the source of supply of this material be from any cause exhausted, the growth of the peninsula becomes checked. In such case the long, low slope at the end of the peninsula, under the influence of the waves, may not only be thrown up against it and be greatly steepened, but the end of the peninsula may be made by such influences to change its direction under the oblique force of the waves, in the manner of the Toronto peninsula. An example of a peninsula built out from a headland many miles across a large bay, and stopped in its growth when only half way across, may be seen in the Gulf of Danzig, in the Baltic.

The longitudinal growth of a peninsula is checked when it approaches a headland of the main shore, by the pulsations which occur in the basin or harbor inclosed by it. Where tidal action exists the basin is filled and emptied twice a day* through the chan-

* NOTE.—The Gulf of Mexico is an exception to this rule; the tide there rises but once a day.

nel between the end of the peninsula and the mainland, and the further encroachment of the peninsula upon this channel is arrested by the currents which sweep through it upon every ebb and flow of the tide. The higher the tide rises, and the bigger the basin which is filled and emptied, the greater will be the magnitude of the channel thus maintained. When the peninsula has reduced the width of the channel to the size absolutely required for the entrance and exit of the tidal water, the channel becomes permanent.

As the magnitude of a channel thus formed is wholly dependent upon the quantity of water which flows through it, it is evident that the quantity must be diminished if a breach occurs in the peninsula, as a portion of the water which would otherwise serve to maintain the channel and stop the growth of the peninsula is lost through the breach.

I think it altogether likely that the Toronto peninsula had its origin in an extension of the River Don westwardly from the southwestern point of Ashbridge's marsh. It is not necessary to sustain such hypothesis; that its ancient channel should have extended through any considerable length of the peninsula. The root of the peninsula being thus formed throughout a distance of a few hundred feet, would be a sufficient nucleus upon which the waves and the current of the lake would concentrate a great part of the sand lying within a few miles of it in water less than eighteen feet deep. To this the easterly gales doubtless contributed a large portion of the detritus from the ancient Scarborough Heights. The prevalence of the southwesterly gales will explain the cause of the change of direction which the peninsula has taken at Gibraltar Point without the Don having ever extended its channel through that part of the peninsula. To the wave action resulting from easterly storms must be attributed the constant growth of the eastern end of the island. This growth will be seen by a comparison of the last survey with those of older date.

It is not however necessary to penetrate the mystery which enfolds the creation of the peninsula. Its continual advancement to the northward conclusively demonstrates the fact that the filling and emptying of Toronto Harbor under the influence of the winds, the rise and fall of the lake and the discharge of the Don, have not been sufficient to arrest the growth of the peninsula in this direction, and the breach at Privat's Hotel which occurred about thirty years ago has made the currents through the main channel since then, still more impotent to check its northward advance.

It is exceedingly difficult to declare with any certainty what is the greatest magnitude of channel that can be maintained permanently through the main entrance to the Harbor without dredging, even if the eastern gap were closed. The annual rise and fall of the lake is a very slow process as well as a very irregular one and produces but lit-

tle current through this channel. The rise and fall of the water in the Harbor under the action of the winds and storms is the chief source to which we must look for the necessary force of current to maintain the channel.

With a tidal basin regularly filled and emptied every day, and a permanent cross-section of channel as a resultant to guide him, the engineer can calculate with great accuracy the increased depth which he can secure by the construction of parallel works to reduce its natural width; but at Toronto the facts prove that the dimensions of the main channel are not permanent, nor are they wholly the result of the currents passing through it, but of the incomplete inclosure of the Harbor by the peninsula. In other words, the western channel was originally an open roadstead. The peninsula has been, and is now, gradually converting it into a channel of permanent dimensions. If this natural process proceeds, it will reduce its dimensions to those which the tidal action or pulsations of the basin enclosed by it, absolutely require for the exit and entrance of the lake water. It will then preserve that size with comparative permanence. Such channel, uninfluenced by artificial causes would be shallow and wide, owing to the low angle of repose which the sands that form its bed naturally assume. If this process were completed, the engineer would know by the natural cross-section of channel permanently established, what additional depth could be secured and maintained through the works he would build to contract it; because the tidal action *will* insure the maintenance of a cross sectional area sufficient for its accommodation, and, if he contracts the area in width, the tidal force will recover a portion of it by increasing the depth through the works, until such area of cross section is made large enough to establish a new condition of equilibrium or permanence, between the force of the current and the resisting forces of friction of the bed and the gravity of the materials of which it is formed. Nothing short of some unusual convulsion of nature could close up the channel between the lake and a basin so large as the Toronto Harbor, if but one channel existed. If instead of one there were many into the Harbor, they would each be shoaler, and in such case, a long continuance of a low lake level, would make them all unusually shallow, and render them liable to be shut up by wave action which would thus convert the Harbor into a lake.

We have, however, in the comparatively stable condition of the inferior channel through the breach a reliable basis for the belief that a channel of sufficient width and depth for the commercial wants of Toronto can be permanently maintained without dredging, simply by the currents resulting from the oscillations of the water in the Harbor, if but one channel be permitted. The channel through this gap has now a central depth of about four and a half feet and a surface width of about nineteen hundred feet, when the level of the lake

s at zero of the gauge. This is equivalent to a cross-sectional area of nearly four thousand feet or of a channel two hundred feet wide and twenty feet of central depth. This channel has been maintained wholly by the currents that pass through it. If the main entrance were completely closed it is safe to assert that it would have been much deeper and proportionately wider.

If it be supposed that the channel through the breach has been maintained by a current sweeping through it, and through the western entrance, at the same time and in the same direction, that is to say, in through one and out at the other, and not by currents induced by the pulsations of the Harbour, it is to be answered that such a current would not have the velocity of those currents which result from maximum differences of level between the surface of the Harbor and that of the lake. A wind blowing continuously from the southeast would have the effect of creating a current through the gap which would flow out of the western entrance, but the same wind would raise the level in Humber Bay at the same time and thus check, if it did not completely arrest such current. The strongest currents which would flow through the gap, without establishing a counter undercurrent would probable be induced by winds from the south or southwest. These would elevate the surface in Humber Bay to a greater degree than at the gap. Their effect upon the water on the south shore of the peninsula would be to create a current, toward Scarborough Heights, without materially affecting the level of the surface at the gap. Storms from the east undoubtedly have the effect of creating considerable current through the gap into the Harbor. I am of opinion, however, that currents thus created through the gap can not have the velocity and scouring power which the under-currents hereafter referred to would possess.

The currents which are induced by a rapid rise or fall of the lake, will have their velocities determined by the slope of surface through the channel, (or fall per mile,) and by the amount of frictional resistance of the bed of the channel. It is evident that when an alteration occurs between the surface levels of the lake and the Harbor, the steepness of the slope through the channel will be increased in proportion as its length is diminished. The slope of the surface creates the current and the friction retards it; hence it is of prime importance that the channel be kept as short as possible. When the currents are the result of winds prevailing for several days in a direction to fill or empty the harbor an undercurrent must always exist through the channel in an opposite direction to that which is seen on its surface, provided all other openings from the lake into the Harbor be closed.

It is impossible for an east wind to sweep over the Harbor for an entire day without creating an outward surface current through the proposed channel, supposing the breach at Privat's Hotel and all

communication with Ashbridge's bay to have been closed. This current will continue to exist so long as the friction of the air sets the surface water in the Harbor and channel in motion, and it is impossible that the water should continue for any considerable length of time to flow out of the Harbor in the direction of the wind, without lowering its surface level. A counter current of equal intensity will then be created below the surface current in the channel. This under current will be the result of hydrostatic pressure induced by the greater height of surface outside of the Harbor.

I should hesitate to advise the construction of a channel of greater dimensions than three hundred feet in width and a central depth of eighteen feet below the present datum plane, although I am not prepared to say that one of greater size cannot be maintained without dredging, after it be once completed.

A channel of the dimensions named can be constructed either at the breach on the peninsula, or at the western entrance to the Harbor, with nearly equal assurance of its permanence. The qnestion, therefore, as to which locality shall be selected for the channel, should be determined mainly by the relative advantages which each would possess for navigation, and the relative cost of each. These are both decidedly in favor of the western location.

So far as to the safety and ease with which vessels could enter either one of these channels during bad weater, there can be no doubt that the preference is most decidedly in favor of the western entrance. Owing to its peculiar position, this entrance is completely protected from storms from every quarter except the southwest. To connect the deep water on the two sides of the peninsula by the shortest route, requires the location of a channel nearly parallel to the direction of these storms; therefore vessels arriving in such weather, would be able to sail directly into the channel and proceed at once to the Harbor.

I have laid down upon the general chart of the Harbor (No. 1), the lines upon which the works that would be required for the eastern gap should be located, if such improvement were deemed more desirable than that of the western entrance. These are shown in dotted lines, and will be readily found on the map. Where these lines are double, the works would need to be equally as strong and costly as the breakwater required on the south side of the western entrance. In addition to the works at the gap, its improvement would necessitate the complete closure of the western entrance by a dyke from the Queen's wharf to the end of the peninsula, as shown also with dotted lines.

On comparing the length of these several lines of works with those hereinafter recommended (the location of which is shown in solid lines on the map), it will be seen that the improvement of the eastern gap would require 4,840 linear feet of heavy work, including 400

feet of the Queen's wharf dyke, and 6,220 linear feet of light work; while the western entrance will require only 2,745 linear feet of heavy work, and only 2,403 linear feet of light work.

In this comparison it is assumed that 500 feet of the landward end of the breakwater, and 1,040 feet of the Queen's wharf dyke, will be of light work. Therefore 2,095 feet less of heavy work, and 3,817 feet of light work, will be required to improve the western entrance.

The amount of dredging required to make the eastern channel would likewise be greater than that needed at the western entrance. With such an enormous difference in the extent of the works and because of the other decided advantages in favor of the western entrance, I have deemed it unnecessary to prepare detail plans for the improvement of the eastern gap. They would only be useful in determining accurately the difference in the cost of each entrance. Whereas, if the eastern one cost no more, I should be unwilling to give it the preference.

If the channel were located at the gap it would need to be about 700 feet longer than the western channel, and the currents through it would therefore be less rapid than through the western one under the same conditions of wind and tide. Hence, they would not maintain a channel of as great a width and depth as the western one. I should not, however, expect to find much difference in them from the injurious effect of wave action at their lake entrances, because either one selected for improvement must first be dredged to the maximum depth required, and as this would be a depth at which there would be little or no disturbance of the bottom at the end of the channel by wave action, there would be but little fear that either channel would require dredging as a result of wave action alone. The lake currents, however, carry more or less sand in suspension, and if this be carried into a channel of greater dimension than the tidal action or pulsations of the harbor demand, they will be deposited in it and will gradually diminish its size to that which can be permanently maintained by the maximum currents through the channel.

To attempt to utilize the present western channel would involve the removal of a large amount of stone by blasting to obtain a sufficient depth, and would moreover require the channel to be crooked, inasmuch as the western end of it would necessarily have to be curved to the southwest to reach the deep water of the lake. Thus located it would require to be very considerably longer than a straight cut across the peninsula. This greater length, and its curvature would be very objectionable. The greater length would increase the friction of the currents flowing through the channel and therefore diminish their velocity. The curvature would diminish their velocity still more, by checking the momentum of the water.

I am confident that a channel 300 feet wide between parallel works, at the western end of the harbor, with a central depth of 18 feet

below the present zero or datum plane, can, when once established by dredging, be afterwards maintained by the natural currents through it, if it be located across the northern end of the peninsula between the lines, shown on the accompanying chart (No. 1), provided all other communication between the lake and the harbor be completely closed.

I have the honor to submit the following

RECOMMMENDATIONS.

1st. The closure of the Eastern Gap with a dyke of sheet piling, protected on the sea side against undermining, with brush and stone.

2nd. The construction of a breakwater and the necessary parallel works to protect and maintain a channel 300 feet wide and 18 feet deep across the northern end of the peninsula, to connect the deep water of the harbor with the deep water of the lake.

3rd. The excavation of the necessary depth and width of channel through the parallel works, after they shall have been constructed.

4th. The closure of the present western channel, after the new one shall have been sufficiently developed to afford equal facilities for commerce, by the construction of a dyke from the western end of the Queen's Wharf to the northern jetty of the new channel.

5th. The closure of all communication between the harbor and Ashbridge's Bay, with a dyke of light sheet piling, or one of earth, three feet above the present datum plane, or zero of the gauge.

All of these works, except those necessary to completely separate the harbor from Ashbridge's Bay, should be located and constructed in accordance with the plans and specifications herewith submitted. The closure of the Eastern Gap, and the construction of the breakwater and channel works, should be executed at the same time to secure the earliest benefit of the proposed improvement. If this be not done, I would then recommend the construction of the channel works and breakwater first, and the closure of the gap while the new channel is being dredged out. I do not think the diversion of the Don into Ashbridge's Bay necessary, except as a sanitary measure. So far as this would affect the channel and harbor, it is probable that the injury which may be done by the small quantity of sediment that the Don brings into the harbor, will be compensated for by the increased current it will give through the channel when in flood. Should it be found a few years after the proposed works are completed that its deposits are injuriously affecting the depth of the harbor, it can then be diverted into Ashbridge's Bay, if it shall not have been previously done for sanitary reasons. It is quite probable that the closure of the Eastern Gap and the growth of the city will soon

make such diversion of the Don imperative as a means of promoting the public health.

Plans are not submitted for the dyking to separate Ashbridge's Bay from the harbor, because this work will be of a simple character, and comparatively inexpensive. I would recommend that its construction be open to competition, with the understanding that each bidder submit with his proposal the plan by which he intends to execute it, leaving to the Chief Engineer the selection of the best and cheapst proposal. This work will be exposed to very little servitude if it be sufficiently distant from the shore line of the harbor to be safe from floating ice. The greater portion of the marsh near the harbor shore is probably already three feet above zero, thus leaving only the sloughs to be closed. In any event, the cost of the necessary work here will not probably exceed $5,000.

If the closure of the Eastern Gap be executed in accordance with the specifications and plans herewith submitted, I am of opinion that a sand beach will be formed in front of the dyke before the parts of it exposed to decay will be destroyed, and that no expenditure for the maintenance of the dyke will be required.

I have the honor to be, sir, with great respect,

Your obedient servant,

JAS. B. EADS.

REPORT

UPON THE SACRAMENTO RIVER.

ST. LOUIS, MO., November 8, 1880.

To His Excellency George C. Perkins, Governor of California:

SIR,—Having been appointed by you a Consulting Engineer for the State of California, it becomes my duty to submit my views upon the proposed improvements " to promote rapid drainage, and to improve the navigation of the Sacramento."

The law under which I was appointed (act approved March 29, A. D. 1878), after creating the office of State Engineer, and defining

in detail the duty of that officer, contains the following provision, viz.:

"Inasmuch as these inquiries involve a broad and scientific treatment of the physical facts of the water system of the State, and as their study may properly be divided, the Governor is authorized to employ, for the purpose of advising and assisting the State Engineer, two Consulting Engineers," etc.

It is quite evident that the great object to be attained is to secure, in the language of the act, "a broad and scientific treatment of the physical facts of the water system of the State." In this report I will give general conclusions, and the reasoning upon which they depend, rather than occupy time and space in the discussion of details that have been carefully considered. This seems to be the desire of your Excellency, for, in your letter of July 28, 1880, you say:

"I would especially call your attention to the report of Mr. Hall, the State Engineer, asking a candid and impartial review of the product of his labors and the correctness and soundness of the ideas advanced by him. * * * All the examinations have been made by the State Engineer. He has ascertained the scope and bearing of this great work, and has proposed clean-cut plans for the treatment of the problems involved, in detail. He has discussed in his report many points of vital importance, upon each of which he has not hesitated to take a firm stand and make definite recommendations."

About the 20th of July last I arrived in Sacramento City, and at once placed myself in communication with Mr. Hall, the State Engineer, who had collected much valuable data bearing upon the important questions I was called upon to consider. Together we went over many details of the surveys, examined the maps and charts, and discussed the subject generally. A few days afterward, in company with the State Board of Drainage Commissioners, my associate Consulting Engineer, Col. J. H. Mendell, U. S. A., and the State Engineer, I proceeded to inspect such portions of the Sacramento River and its tributaries, and the injured lands adjacent to them, as it was deemed necessary for me to examine, in order to fully inform myself of the magnitude and prominent features of the problem to be solved. My inspection of the Sacramento River extended from San Francisco to Chico Landing. I saw the Feather River, in the vicinity of Oroville, and inspected it from Marysville to its mouth. My inspection of the Yuba River extended from the foot-hills, near Smartsville, to its junction with the Feather River, and I also examined the Bear river, in the vicinity of Wheatland. I visited several of the largest hydraulic mines, and made myself acquainted with that system of mining, so far as it affected the questions under consideration. During this inspection, and afterwards at Sacramento City, Col. Mendell, the State Engineer, and I discussed the principles involved in the problem, the methods proposed by Mr. Hall for arresting the debris in the vicinity of the mines, and for the correc-

tion of the main river and its important branches, and considered in detail all matters having an important bearing upon the subject. Since my return home I have examined other data not then available, but which have recently been furnished me by Mr. Hall.

According to the estimate of the State Engineer, the Valley of the Sacramento is about 150 miles long from the Iron Canon to the mouth of the Mokelumne River, and its greatest width at right angles to this line is 50 miles. It contains about 4,769 square miles. During the high water of March, A. D. 1879, about 847 square miles of this area were covered with water. The length of the Sacramento River, between Iron Canon and Suisun Bay, is about 250 miles. The mountain watersheds whose drainage systems are tributary to the Sacramento are, in combined area, more than two and a half times the area of the valley itself. Violent rains, during the winter and early spring, cause these mountain basins to send down floods of considerable magnitude, and the melting of snows in the higher regions causes other flood waters to flow down the principal streams during the later spring months. The streams which enter the Sacramento Valley are all subject to certain freshets, but these are generally of short duration. Occasions are extremely rare when all the streams are in high flood at the same time. Ordinarily the waters of one freshet are nearly out of the valley when another comes into it. The rains which fall in the valley, unless they are exceptionally heavy, are absorbed by the soil, and do not materially contribute to the swelling of the water in the rivers.

The channel of the Sacramento being of insufficient capacity for the immediate passage of ordinary floods to the sea, a large portion of the water escapes over its banks, or is carried by natural sloughs into extensive basins which exist on each side of the river through many miles of its course. These basins are filled during each flood, and after its subsidence the water gradually finds its way back into the river through inlets, or sloughs, at the lower end of the basins. There is great variation in the capacity of the channel of the river in its different parts. Thus, for instance, throughout a distance of 106 miles *above* "Butte slough" there is a channel of larger dimensions and slope than exists through a distance of 64½ miles *below* it. This remarkable phenomenon results from the fact that a large portion of the river floods have annually escaped by "Butte slough" into the "Sutter basin," which is of great extent. The channel through this 64½ miles is extremely tortuous, owing to the same cause. The water which escapes here is not again returned to the river until it reaches the mouth of Feather River, at the lower end of the basin. The distance through this basin, from its inlet to its outlet, is only about half as great as it is by the crooked channel of the river.

The Feather River is the only outlet which acts as a main drain,

and in that capacity is an auxiliary to the Sacramento throughout the middle portion of the valley. It receives the waters of the Yuba and Bear Rivers and other smaller streams, and is the largest affluent of the Sacramento.

The levees which have been constructed have not been built on any uniform plan, and inclose high-water areas of very different widths. The regimen of the stream has, in consequence, been interfered with in a way to still further impair the even capacity of the channel. The floods are now confined for comparatively long distances, and then escape laterally in large volumes through natural sloughs, or by crevasses in the levees. These crevasses frequently occur, and many have remained open for years.

The evil effects of these disturbances of the regimen of the river have been greatly aggravated by the detritus carried into its bed from the hydraulic mines located near the canons tributary to it.

Mr. Hall estimates the total amount of filling in the beds of the Feather and Sacramento Rivers, from Oroville to Collinsville shoals (about 163 miles) to be nearly 134 millions of cubic yards. He estimates the average depth of the fill in the Feather River, from the mouth of the Yuba to Nicolaus (19.6 miles), to be 20 feet; the average fill in the Sacramento, between the mouth of Feather and American Rivers (19.74 miles), to be 15 feet; and from American River to Grand Island (27.7 miles), to be 10 feet. The total fill throughout 163 miles will average 9 feet in depth by 460 feet in width. Of course the estimate of this enormous quantity is only approximate, but the care with which Mr. Hall has made the investigations, and the reliability of nearly all of the data upon which the totals are based, entitle the results obtained to much confidence.

The effect of the detritus upon the Yuba and Bear Rivers has been much more marked than in the case of the Feather and Sacramento. In these tributary streams the original channels have been wholly filled up and obliterated, and the waters, overflowing the banks, have transformed a formerly fertile region into a barren wilderness. Once these streams were pure and clear; there were fields producing valuable harvests, extensive orchards, and substantial houses. Now these are all buried in the mass of earth which the uncontrolled floods have deposited, and prosperity has given place to desolation.

With reference to the extent of the injury to the inundated lands Mr. Hall says: "Reviewing the losses which are capable of estimation, we find an aggregate area of 43,546 acres, which have suffered a depreciation in value of $2,597,635."

The present annual discharge of mining detritus into the Feather, Yuba, Bear, and American Rivers is estimated by Mr. Hall to be 53,404,000 cubic yards. This would cover nearly 17¼ square miles three feet deep. In the removal of this enormous amount of material, 15,122,000 miner's inches of water are used annually in the mines

from which it is discharged. A miner's inch of water is a unit of measure intended to represent a definite quantity discharged in 24 hours, and is variously estimated at between 2,000 and 2,600 cubic feet (or about 89 cubic yards), making a total of about 1,350,000,000 cubic yards per annum, an amount equal to the total discharge of the Sacramento for 8 days and 10 hours, when flowing at the rate of 50,000 cubic feet per second.

There can be no doubt that the vast quantity of detritus flowing from the mines into these channels is the chief cause of the changes occurring in the regimen of the rivers. Some portion of the sedimentary matter transported by them is supplied by the lands near their margins, but as the valley of the Sacramento, excepting a small portion of its central area which is occupied by the "Buttes," is a level plain, with a soil that rapidly absorbs all rains not exceptionally heavy, the amount contributed from this source must be insignificant, while that supplied by the mountains, before they were affected by hydraulic mining, seems, from abundant testimony, to have been insufficient to obscure the former clearness of these streams.

It is very certain that unless a proper plan of improvement be adopted, there will be still greater inundations, and more extensive areas of valuable lands will be covered with this detritus. Navigation must likewise become more difficult, and in time that of Suisun Bay and the Bay of San Francisco will be impaired.

No improvement is worth considering which will not result in permanent relief, and no improvement can afford such relief unless it be consistent with certain well-known natural laws controlling the action of all sediment-bearing rivers.

An intelligent judgment can not be formed as to the proper means of relief without some general knowledge of these laws. For this reason I will explain the principal ones having a bearing upon the movement of waters in rivers, and the transportation of the sediment with which they are charged.

Motion can only occur by the expenditure of *force*, and hence all questions relating to the movement of the floods and sediment, the force impelling them, and the resistance they encounter, belong to that branch of science known as dynamics. A knowledge of the great yet simple truths upon which this science rests is easily acquired, and will enable any one to comprehend the problem presented, and judge of the correctness of any general treatment proposed. It enables the engineer, by the aid of mathematical processes, to very accurately estimate the amount of force developed by the movement of the waters through any part of their route, and to ascertain the amount of the various resistances (or other forces) which must be overcome by the force of the river at any part throughout its course. The total sum of these resistances is called,

in scientific parlance, *the work done;* and it is an axiom, not to be forgotten as we proceed, that the force expended by the river in any given time must be exactly equal to the work done in that time.

We have, therefore, two grand divisions in the problem—*force* and *resistance;* and to one or the other of these belong all parts of our investigation. The force expended by the river results from the fall of its waters from a higher to a lower level. To estimate the amount of any moving force, three elements must be considered: first, *matter;* second, *space;* and, third, *time.* In this case we have—first, the volume of the water in motion; second, the vertical height from which it falls; and, third, the time during which it is falling. If either one of the two first-named elements be increased during any given unit of time, the force expended during that time will also be increased. That is to say, if the volume of discharge be increased, the force will be increased. Or if the height from which it descends be increased, the force will be likewise increased.

The various resistances overcome by the force of the river consist of—first, the friction of the bed; second, the friction of the particles of water among themselves; third, the resistance to the direct flow of the water resulting from the bends and irregularities of the channel; and, fourth, the resistance of the gravity of the sedimentary matters in the water, when suspended in it or moved along its bed.*

It is simply impossible to compel the current to do any additional work beyond that performed by it in a state of nature, unless the force expended be increased, or unless some one of the resisting forces before named be proportionately lessened. We can not make it turn a mill-wheel, or absorb any portion of its force, even by the friction of a fish-net stretched across its channel,† without lessening the force which holds its sediment in suspension. It is this simple law of nature, namely, "the work done can not exceed the force expended," which makes the construction of a machine capable of perpetual motion an impossibility. How impossible, then, is it for the river to transport an immense quantity of mining detritus without exhausting a part of the force which is required to overcome the friction of its bed. If the force necessary to do this be diminished, slower currents must result, the drainage of the valley be impaired, and the floods raised to greater heights.

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* The resistance caused by winds is not included here, because it is so small and variable a factor in the problem. The tidal force is also omitted, because the resistance of the incoming tide is compensated by that of the ebb.

† This fact was verified literally on the Missouri River last year. Screens of No. 10 wire, having meshes about one foot square, placed across the current, with their lower edges anchored by bags of stone, and their upper ones sustained by large buoys, caused such rapid deposit of sediment below them as to raise the bottom in some cases as much as sixteen feet during one flood season.

There are but two ways of increasing the force of a river. First, by increasing its volume; second, by increasing the vertical space through which its volume descends in a given time.

Nature gives to all sediment-bearing rivers the ability to increase their force when overtaxed by their burdens of sediment. This they do by depositing the excess in their beds, thereby raising them, and increasing their surface slopes, or, as it is popularly called, their "fall per mile." An increase of this slope involves an increase of the vertical space through which the water falls, and this increases the force, and creates a greater velocity of current.* This deposition in the bed continues until a velocity is produced sufficient to transport the whole of the sediment to the sea, after which deposit ceases to occur in it. If the filling of the bed of the stream in this manner be not sufficient to produce the necessary current, the waters expand over the adjacent lands, and cover them with sediment, until they are of sufficient height to sustain new channels of the requisite slope.

The Sacramento River and its tributaries have evidently been doing this kind of work for the last score of years. Near the mines, we learn from Mr. Hall's investigations that the Yuba now falls from an increased height of 125 feet, and the bed of the Sacramento at Feather River is twenty feet higher than it was formerly.

By far the most important element of *resistance* which prevents the rapid flow of the waters of the valley, is the friction of the different channels through which they move. Some idea of the magnitude of this resistance may be inferred from the fact that nearly nine-tenths of the resistance of well-formed ships is the result of friction between their surfaces and the water. If we can reduce this resistance in the river channels, we can not only facilitate the discharge of the floods, but we will have a corresponding amount of surplus force to excavate deeper ones in the rivers and to transport the sediment.

The amount of frictional resistance depends upon the extent of the area in contact with the water, and arises from the mutual cohesion of the fluid particles, and from their adhesion to the surfaces over which they slide. Hence, if a stream be excessively wide, the friction will be reduced by reducing its width, and an acceleration of current must result, although the surface slope may be no greater than before. If we use two pipes for drainage, one being one foot in diameter and the other four feet, each being the same length, and each having the same head of water, or slope, the frictional area in

* The surface slope in flood time, and not the surface slope at low water, is that to which I have reference throughout this report, and this slope must not be confounded with the irregular slope of the bottom of the channel. *Force* is increased or diminished by the *surface slope*. The slope of the bottom only increases or diminishes *resistance*.

the larger pipe will be only four times as great as it is in the smaller one, yet it will contain sixteen times as much water. This is because the surface in contact with the water, and which causes the resistance, increases with its diameter, while its area increases with the square of its diameter. The friction in pipes is therefore inversely as their diameters. The form of channel which offers the least frictional resistance to the flow of water is semi-cylindrical, and, in proportion as the channel departs from this form, widens and becomes flatter, this resistance increases, and the surface slope has to be steepened to produce the same velocity of current. This steepening of the slope is the direct cause of the overflows.

The magnitude of the channels of rivers flowing through alluvial districts is determined by the size of the floods that pass through them. At such times the force of the river is not only much greater, because of the increased volume and slope, but because the ratio of friction per unit of volume is greatly decreased; hence, there is a much greater surplus of force. This surplus increases the velocity of the current, and gives it greater ability to transport sediment. If the channel be too small at any one or more places, the surface above rises, and a steeper slope is thus made through the contraction; the current velocity is thus made greater there, and the extra amount of sediment which can be then carried by the water will be taken up out of the bed of the stream, and thus it will be deepened. As this deepening progresses, the slope is lowered and the velocity reduced.

Friction is not only increased by the widening and flattening of the channel, but also by its subdivision. If we divide the water flowing in one semi-cylindrical channel into two equal ones of half the size, we must increase the slope of each of the smaller ones in the ratio of 12 to 17, to produce the same velocity; because the frictional area of the two smaller ones will be five-twelfths greater than the larger one. To show that an increase of slope occurs from this cause on the Sacramento, we have only to compare the slope of Steamboat slough, where the river is divided into two channels by Grand Island, with the slope of the river above it. The high-water slope of this slough is fifty-seven hundredths of a foot per mile, while the slope of the river above and below it is only forty-three hundredths. When the entire volume is made to flow through Steamboat slough, as Mr. Hall proposes, a lowering of fully twenty inches in the flood height at Sacramento can be confidently looked for from this improvement alone.

If the main river were divided into many different channels, the increase of slope would be still greater. If it were divided into four equal channels, each having one-quarter of the capacity of the main channel, the area of the surface of their beds would be twice as great as that of the main channel, and the slope of the surface of the

water would have to be doubled in that part of the river to produce the same velocity in them.

At Butte slough the water is divided into two channels, one of which, viz., Sutter basin, is of enormous width, and, consequently, the frictional resistance to the flow through it is also enormous. The other is the main channel of the river, and in this the ratio of frictional resistance to the volume carried is also much greater, owing to the diminution of the volume in it. This resistance is also increased by the great amount of *bend* resistance in this part of the channel,* and the result is that the river here falls nearly one foot per mile from Butte slough, through Sutter basin, to Feather River, while below Feather to the American the fall is only one-third as steep.

With such evidences of the increase of slope which inevitably follows the widening of the surface over which the floods pass, or the subdivision of the main channel into smaller ones, it seems astonishing that any one can seriously propose to give permanent protection against overflows by multiplying the channels through which the floods now struggle to reach the sea. Those who advocate such means of relief have yet to learn two or three of the grandest but simplest laws controlling the motions of matter throughout every part of the universe. They have yet to learn, first, that no atom of sand or water in the river, or planet in space, can have motion except through the impulse of *force;* second, that matter in motion must encounter the *resistance* of some other force or forces; and, third, that the *velocity* of the matter depends upon the amount of force urging it onward, and the amount of resistance retarding its progress.

Friction being the chief element of resistance, and this being greater and greater in proportion as the water is subdivided, the advocates of drainage canals and other outlets propose to increase the velocity of discharge by *increasing* the friction which retards that velocity; or, in other words, they propose to reverse the laws of nature.

As the immediate effect of a crevasse is to lower the height of the flood in its vicinity and below it, many persons imagine that natural or artificial outlets, by which a part of a river's flood volume is drawn off, tend to lessen the recurrence of destructive inundations.

This process would undoubtedly prove effective, if the waters of the Sacramento were not charged with an immense quantity of sediment. To prevent this settling on the bottom, a certain velocity of current must be maintained. Rivers flowing through beds formed

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* Bend resistance differs from friction. It is the force which changes the rectilinear motion of the water, and absorbs, therefore, a certain portion of the impelling force.

of their own deposits must almost always have their waters charged with all the sediment which the water will sustain. One of the dynamic elements of the force of the river is its volume. If a portion of this passed out through the crevasse, it is absurd to suppose that the force remaining will be as great as before; and, as the ratio of frictional resistance must increase in proportion to the remaining volume, it is equally absurd to suppose that the diminished force can impel the diminished volume with the same velocity, where there has been no increase of slope. The equilibrium which had previously existed between these forces being disturbed by the creation of a new outlet, the river at once sets up a natural process for its restoration. As it can not prevent the loss of one element of its force, through the outlet, it proceeds to increase another one of them. It begins at once to increase the height, or vertical space, through which it falls; that is, it increases its surface slope, by the deposit of material in its bed, and it continues this process from the outlet down to the sea, until it is so steep that a restored velocity prevents further deposition in it.

The current being insufficient to sustain the entire burden of sediment after it passes the outlet, the excess falls immediately below it, and, by shoaling the channel there, restores the velocity over the shoal, but not below it: the result is, that the shoal is extended on down, if the outlet remains permanently open, until repeated floods reduce the size of the entire river from the outlet to tide level. But it does not stop when this is done, for the reason that the ratio of friction to volume has been increased, and a greater slope than the original one must be produced to create the velocity necessary to prevent further shoaling. Therefore, although the first effect of a crevasse or natural outlet is to lower the height of the floods, the final and permanent one is to increase it in proportion to the magnitude of the outlet, because the slope of the river must be increased in proportion as the volume is diminished.

The proof that such change will occur in the river's slope is shown by the fact that the slopes of silt-bearing streams flowing through alluvial deposits, all over the world, are in an inverse ratio to their volumes; that is to say, where the volume is small, the slope is great, and conversely.

What has been said of outlets thus far relates to those from which the waters do not again return to the river. Whether they return or not, however, an island is formed by the division of the water. If it returns, the increase of slope will extend only from the outlet to the point where the water again enters the river. The same phenomena occur in island channels. If two channels inclosing an island be of equal size and length, they will be permanent, unless one or the other becomes obstructed by some accidental cause; but if one be much longer than the other, the river can not increase the slope of

the longer, because it would be controlled by the shorter one, and ultimately the latter, because of its greater slope and current, would become the main river, while the former would be separated from it by deposits formed in the sluggish waters at both ends of it. The longer one would thus become a lake of the character frequently seen near the main river, in alluvial districts.

If the alluvial deposits through which Butte slough is formed were less firm, the enlargement of that outlet would be so rapid that the main river would probably soon flow through it, forsaking entirely the tortuous channel between Butte slough and Feather River. In any event, if Butte slough be left open, the sediment which enters this basin must in time reduce its width, and form a well-defined channel through it, to the still greater injury of the main river. The route through the basin to the mouth of the Feather being but about half as long, and therefore twice as steep, the tendency of the river to at once take that route is only checked by the capacity of the slough and the frictional resistance to the flow of the water over the wide bed of the basin. Its early closure and the straightening of the river by cut-offs between the slough and the mouth of the Feather, as proposed by the State Engineer, can not fail to improve the navigation of the river and lower the height of the floods.

As a shoaling of the channel, an increase of slope, and higher floods are the inevitable results of a loss of volume, it is apparent that these phenomena are all reversed by an increase of volume. And as the expansion of the river-bed into excessive widths, or its subdivision into numerous channels, increases the resistance, thereby causing a shoaling, steeper slopes, and higher floods, it is equally apparent that, by narrowing the wide places and compelling the water to flow in but one channel, shoals will disappear, the slope be lowered, and flood lines be reduced. An increase of resistance is equivalent to a loss of force, so far as velocity is concerned, and it follows, therefore, that the same evils will result from an increase of frictional area as those resulting from a loss of volume. These causes have both combined to hasten the injury to the channels of the Sacramento and its tributaries. Their beds being raised by sedimentary deposits, the frictional resistance has increased with the diminished size of the channel, and, at the same time, the loss of volume by the overflow of the banks has been greater and greater with the elevation of the flood heights. This fact is of value, for it shows that beneficial results will in like manner speedily follow the proper management of the two great elements, *force* and *resistance*.

The channel works proposed by Mr. Hall are designed to lessen the resistance by gradually narrowing the wide places, closing Old River channel at Grand Island, and lessening the bend resistance near Knight's Landing, by making certain cut-offs to straighten the chan-

nel in that neighborhood, and other less important improvements. These corrections would soon enable the channel, without overflowing, to receive more flood water, and this would be an increase of force.

Any correction which would compel all of the waters to flow in their proper channel, within any very brief period, is not to be thought of. This would have to be the work of probably fifteen or twenty years. But, by pushing the channel works and strengthening and elevating the levees a little at certain localities, the closing of the present outlets in the gradual manner proposed by Mr. Hall may be done without increasing the danger of overflow, provided the works for arresting the mining detritus be then constructed.

Great doubt has been expressed by many intelligent persons as to the possibility of giving such capacity of channel to the Sacramento as will enable it to discharge the entire flood waters of the valley.

In considering this we must remember that the capacity of the river to discharge floods will be greatly improved, without any enlargement of it, so soon as it is brought to an approximate uniformity of width and depth, and its most tortuous parts are straightened. It is difficult, if not impossible, to estimate accurately how much more water it will then be capable of discharging, because the quantities of some of the elements of the problem are so difficult to ascertain; but we may safely assume that, with no greater flood elevations, it will, when thus improved, discharge fully fifty per cent. more than at present. The effect of such an increased volume will be to deepen the bed after the rectification of the channel is effected; and this process will continue until a lower surface slope reduces the velocity so much that it will be only capable of carrying the sediment poured into it by its tributaries without taking up any additional quantity from its own bed. If we suppose that this much deepening of the bed and reduction of slope have occurred under the impulse of fifty per centum added to its flood discharge, and the deepening to have then ceased, the surface slope will then have been so greatly lowered that much more than fifty per centum may then be added to that increased volume without raising the floods beyond their former height. Each increment added to the flood volume produces increased velocity, which in turn gives the water increased power to carry sediment, and the extra amount of this is picked up from the bed by the rapid current, until the bed is so much deepened that a lower slope of surface ensues. This gradually reduces the carrying capacity of the water to that velocity which is unable to produce a further deepening of the bed. When this is done, a condition of stable equilibrium is again established between the several impelling and resisting forces. In this manner streams lower their surface slopes throughout alluvial districts, in proportion as their volumes are increased. The South Pass of the Mississippi is twelve

miles long, and the Southwest Pass is eighteen. They separate at a point where the river, in flood, is about three feet higher than the mean level of the Gulf; consequently, the shorter one has a slope of three inches per mile, while the longer one has but two inches. This difference of slope is because the steeper one discharges but one-quarter as much water as the other. If the volume of the larger were discharged through the smaller channel, it would rapidly deepen and enlarge it, and take a lower slope of surface. The main river, which is nearly three times as large as the larger pass, has, owing to its immense volume, only about one inch and one-third fall per mile in this vicinity. Alterations in the slope of the Mississippi have been observed by the exact measurements of the Mississippi River Commission, and those of the U. S. Engineers, which leave no room to doubt these changes; and they are known to result from such causes as I have explained. As the slope is gradually lowered by each addition to the volume which the channel is compelled to receive and carry, the capacity of the Sacramento, like that of all other streams flowing through their own deposits, will be only limited by the volume it is compelled to carry; and, as the lowering of the slope brings the flood surface, at first, below the top of the levees, and finally below the tops of the banks, as the volume is increased, and so on still lower, if the volume be still more increased, it follows that, when the channel is once corrected, the volume can be more rapidly augmented each succeeding year, and thus what may at first seem a paradox becomes a reality—namely, the larger the volume of the floods carried in the river, the less will be the need of levees. It is, however, only in proportion as we ascend the river that the benefits of the reduced slope will become apparent, because one end of the flood line is at the sea (or tide level), where the proposed works can not alter it. But the lowering of the river floods at Sacramento City below the natural surface of the land there, after a proper correction of the channel shall have been made, will be a question of the volume of discharge through it. If this be sufficiently increased, the flood line can be permanently kept below the lands, in the vicinity of the city, without levees.

Fears have been expressed that the width of the river will have to be greatly increased, if the attempt is made to discharge all of the flood waters through it, and hence much valuable land will be lost on each side of it by the enlargement of the river.

Here, again, the lessons which are drawn from observing the capacity of different-sized pipes to discharge water can be used to advantage to enable us to form a correct judgment upon this question; for the same laws control the flow of water in pipes and in river channels. Experiment and practice have proven that, to increase the discharge of water 22 per centum through a long pipe with any given slope, it is only necessary to increase its diameter one-

twelfth. If the diameter be increased one-quarter, the discharge will be increased 75 per centum, while to double the discharge it is only necessary to increase the diameter one-third. If the diameter be doubled, the discharge will be more than five and one-half times as great. To double the capacity of the river where it is of good form would require about 166 feet additional width, assuming the width at this time to be 500 feet and the slope to remain unaltered. From these facts it must be evident that the fear of any inordinate enlargement of the river is groundless.

It has been shown that the greatest channel-making power of the stream is exercised during its floods. Hence anything which lessens the volume of the flood reduces its ability to deepen its bed and lower its slope. The retention of so large a portion of the pluvial waters (or rainfall) of the valley in the hydraulic reservoirs of the Sierra Nevada has this tendency. Last year about 847 square miles of the valley were covered with flood water. The amount of water reservoired and used during the same year, according to Mr. Hall, was about 1,350,000,000 cubic yards, or enough to have covered one-half of the surface overflowed three feet deep. In the present condition of the Feather and Sacramento, it would not be desirable to have this additional quantity added to the annual floods. When the channels of these rivers are finally corrected, and the remainder of the floods gathered in them, the addition of these reserved waters, no longer loaded with mining detritus, instead of being hurtful, would result, as we have seen, in positive benefit, by conferring upon the river increased power to further lower its flood line, should the exhaustion of the mines make it then desirable to liberate them. These facts should not be overlooked by those who would cure these evils by stopping the process of hydraulic mining. It is hardly to be supposed that the expense of maintaining the reservoirs and regulating the discharge of such a vast quantity of water would be incurred if the mines ceased to use it.

As large areas of shoals which are now more or less exposed at low water must, as a result of the correction of the river, necessarily be built up to very nearly the height of the natural banks by the deposits which will be removed from the shallow channels, and as many deep pools existing below the sand-bars in the narrow parts of the river will be filled with the bar material removed, there is no occasion to fear that the rectification of the river will materially increase the amount of the deposit occurring in the bays in the lower part of the river. In the slow process of nature uncontrolled by art, Suisun Bay would gradually be reduced to the width of the river proper, and the Bay of San Francisco would in time undergo a similar change. But it should be remembered that it is the maximum tides and floods which determine the magnitude of sedimentary channels. Hence the rapid drainage of the valley, by increasing the force of the

floods, will promote the discharge of the sediment into the ocean, for it will aid the tidal action in keeping it suspended until the greater part of it is finally discharged there. The sediment left in the water, after the construction of the proposed works for arresting the mining detritus, will settle much more slowly than that which now flows down, and must make the injury to the bays a very slow and remote occurrence.

With respect to the influence of the tides upon the lower portion of the river, it is only necessary to say that the same laws we have been discussing apply with equal force to the motion of tidal waters in river channels. The inward and outward flow of the tides will create and maintain a channel in proportion to the maximum volume and slope of the ebb tide passing through the channel. Hence, where a tidal basin of great extent occurs, as at Port Royal, New York, and San Francisco, the channel through which it is filled and emptied will be proportionately large, and, as the depth and width of the river channel increases, the tidal water will enter with less frictional resistance, and the volume of the ebb will be proportionately greater. Therefore, as the improvement of the lower part of the river channel progresses, the force of the tidal action will increase and aid in maintaining such capacity as the combined influence of the river floods and tidal action, under a better system of drainage, will create.

The method proposed by Mr. Hall for arresting the mining detritus at the foot-hills has been fully explained by him, and is upon the same system substantially as that recommended by the Mississippi River Commission for the improvement of that river from Cairo to the head of the passes. This system has been successfully applied at the mouth of the river, and, more recently, at points on the Missouri. It is based upon the intimate relation which exists between the velocity of the current and the quantity of sediment it carries. As the slightest retardation of the current will cause the water to deposit a portion of its sediment, it is proposed to place, on the Yuba River, open (or pervious) brush dams across the lower end of the canons out of which the detritus flows, where the foot-hills are a mile or more apart, and where the detritus has filled the valley from hill to hill. These dams would be placed from 200 to 400 feet one below another, but would be intermitted at such parts of the valley as are covered with densely growing willows. They would be only three or four feet high, except where they would cross the channel of the river. At such places the dams would be of more permanent construction, so as to obliterate the channel and spread out the water more uniformly over the space on which the dams are intended to arrest the sediment. In this way the frictional resistance of the bed is increased, and, as the water passes through each successive dam, its velocity is reduced, and the heavier portions of its

sediment accumulated between the dams and in the brush. The water which finally passes off will contain only the lighter detritus, which can easily be carried by the river. Each year new dams would be built upon the deposits thus accumulated; but, as the old ones would probably send forth a growth of willows, the renewal of the dams on the deposits would be less necessary each year. In this way the deposits would be arrested over an area of two or three miles in length, and of the width existing between the foot-hills. The continually increasing height of the deposits would soon cause the mass to raise the water in the valley above it, and thus add to its effect that of a settling basin. The willow dams would be of the cheapest possible construction, and they would only need to be strong enough to stand in the rapid water without sustaining any appreciable head or hydrostatic pressure.

This method of treatment would be modified at other localities to suit the conditions presented at each, according to the judgment of the State Engineer. Below the areas on which the detritus would be thus impounded the waters would be collected by cheap willow constructions into one channel of an approximately uniform width, through which they would be carried to the larger streams. This correction of the smaller tributaries would soon cause them to deepen their beds, and render the maintenance of the levees near them less and less necessary.

The correction of the Feather and Sacramento rivers would be effected by similar methods, modified to suit the conditions presented at each locality. Light brush dams or screens would be constructed across the shoals where the rivers are too wide, and an improvement in the general alignment would be made at certain places. In doing this, willow spur dykes and dams of stronger construction would be used, and in some places loaded with stone or strengthened with piles, and the banks, where they required protection, would be revetted with willow mattresses. The closure of the outlets would be made with willow mattresses, earth and stone, or other materials. The chief object of these works would be to effect an improvement in the alignment of these rivers, and to bring their channels to an approximate uniformity with the width of the well-formed parts of them.

For a more exact knowledge of the character and details of the works suggested, and of the localities where it is proposed to apply them, reference is made to the appendix to this report, and to plans and specifications prepared by Mr. Hall.

In conclusion, I beg to state that I have carefully read Mr. Hall's reports on this subject, and think he has treated it with much ability. In the main I concur with him in the views expressed, so far as they affect the question of a proper remedial system of improvement. The schedule hereunto attached, addressed by Mr. Hall to

Col. Mendell and myself, giving the localities and the general method of correction proposed at each, has been carefully examined by me, and the several improvements therein suggested meet my approval. It is important that the proposed corrections in the lower part of the river, especially that at Steamboat slough, should be commenced and urged forward as rapidly as those above. If the entire system be properly executed and fully completed, as proposed, I have no hesitation in asserting that the results will be most gratifying and remunerative.

I have the honor to be,

Very respectfully,

Your obedient servant,

JAMES B. EADS,

Consulting Engineer.

TEHUANTEPEC SHIP RAILWAY.

ADDRESS BEFORE THE HOUSE SELECT COMMITTEE ON INTER-OCEANIC CANALS, 9TH OF MARCH, 1880, IN REPLY TO COUNT DE LESSEPS.

In commenting upon the project of Count de Lesseps, I shall consider the subject simply as an engineering one, and in relation to its practicability, its probable cost, the time needed for its completion, and its utility when completed.

The question of the practicability of opening a tide-level waterway through the American isthmus is simply a question of money and of time. If sufficient money were supplied, and time enough were given, I have no doubt that, instead of the narrow and tortuous stream which Count de Lesseps proposes to locate at the bottom of an artificial canon to be cut through the Cordilleras at Panama, engineers could give to commerce a magnificent strait through whose broad and deep channel the tides of the Pacific would be felt on the shore of the Caribbean Sea, and through which the commerce of the next century might pass unvexed, from ocean to ocean.

The science of engineering teaches those who practice it how the forces of nature may be utilized for the benefit of mankind, and it is

the duty of an engineer when charged with the responsibility of solving an important engineering problem, by which his fellow men are to be benefited, to consider carefully how the desired results can be most *cheaply* and most *quickly* secured. Therefore, it is his duty to consider every method for the accomplishment of the end in view which science and nature have placed within his power, and to select from the fullness of their stores such methods as the precise teachings of mathematics and a knowledge of the laws which control the forces of nature assure him will certainly accomplish the desired result in the least time and for the least money.

Where the growing demands of commerce, at the crossing of a river are no longer met by the use of a ferry, the engineer suggests a bridge, and to prevent injury to the commerce of the river, and save the cost of an excessive height in the structure, he plans in its roadway a draw that may be opened for the traffic of the river, and closed for the traffic of the land. If the traffic of either be too great to admit of interruption, he is then justified in erecting a higher and more costly structure, which shall let the commerce beneath it pursue its path uninterruptedly, while that which demands a transverse route will pass over a permanent highway. But his profession in such case likewise suggests another alternative. It is possible to bore through the earth beneath the river, and thus open an unobstructed path by other means for the transverse commerce which has grown too great for the ferry. Before recommending the costly bridge, it is his duty to investigate the merits of the tunnel also, and if he find that to be the cheaper and the quicker remedy, he should lay the two plans, with all their advantages, with his advice in the premises, clearly before those who are to pay for the work.

When the commerce between the east and west shores of the Atlantic grew so great and impatient in its demands that the winds of heaven no longer sufficed to hurry it on, the world was startled with the proposition to harness another one of nature's forces to the car of commerce, and the expansive property of steam was thereupon immediately applied in the propulsion of ocean ships. Men whose thoughts had been confined to one channel alone shook their heads in doubt, although for many years before they had seen the same force applied to vessels engaged in river navigation. When the Thames Tunnel was proposed, where the river traffic at the locality interdicted the erection of a bridge, the same class of men again shook their heads, because to them the antiquated ferry-boat was the sole solution of the problem. They knew it was as old as the canals of the Pharaohs, and their prejudices in favor of old methods led them to look with doubt upon this plan of crossing a river; but now, tunnels under rivers are recognized as one of the approved methods of engineering.

Large, fertile, and valuable tracts of land have been reclaimed by

cutting canals in which the superincumbent water could flow off to lower levels, but when engineers proposed to reclaim the land which was once covered by the lake of Haarlem, by a reversal of this method, and, by the use of steam, proposed to lift up the water of the lake into canals many feet above its bed, the doubters again shook their heads; but it is now proposed to apply the same successful method to reclaim the enormous area covered by the Zuyder Zee.

The ancient bridge-builders excluded the water from their shallow foundations and began to build the piers for their bridges at the *bottom* of the river, but the commerce of late years has demanded bridges where it was necessary to sink the piers in much profounder depths, and the engineers of the present age have reversed the old methods, and begin the building of the piers of their bridges now on the *surface* of the river, and sink single masses of masonry weighing forty thousand tons, through immense strata of alluvial deposits, down to the bed-rock at great depths below, by scientific methods totally unknown to the ancients.

It should be borne in mind by laymen that the science of engineering is based upon natural laws that are absolutely unalterable—laws that are, therefore, absolutely reliable; and that through the control which scientific discovery has given to the engineer over the forces of nature, the only limit to the possibilities of his profession lies almost wholly in the COST of the works which he proposes to execute. For this reason, the limit which should control the magnitude of his projects should not exceed the real necessities and the financial abilities of his fellow men But should there occur a pressing need for a tower so high that it shall penetrate the regions of eternal snow; or an arch so vast that its span may be measured by the mile; or a tunnel through the broadest base of the Rocky Mountains; or a railway that shall transport, entire and uninjured, the grandest of the Egyptian pyramids; or a channel through Darien big enough to disturb the flow of the Gulf Stream and alter the pulsation of the tides; you may be assured that each and all of these things, and much more, are within the possibilities of his profession, if you will only furnish the money to pay for them. Hence any intelligent engineer, having a just conception of the immense capabilities of his art, will at once concede that it is entirely possible to cut the little passage through the Isthmus of Panama, twenty-eight feet below the ocean level, as proposed by M. de Lesseps, provided the money be supplied to meet the cost. But if an engineer be asked to estimate accurately the cost of such a cut, he will tell you that there is one important element of expense in the plan which it is impossible to ascertain with any degree of accuracy. He will tell you that so long as the bottom of the canal is kept *above* the ocean level, the average rainfall at Panama will enable him to estimate with some degree of certainty the probable quantity of drainage water that must be taken care of

to enable the work to progress uninterruptedly. But when the ocean itself is tapped, as it must be in cutting the canal twenty-eight feet *below* its surface, natural methods of drainage become impossible, and the quantity of water which will probably enter through veins and fissures below the ocean level, in the uplifted and disturbed stratification of the Cordilleras, through which the canal is to be cut, is an unknown quantity, which engineering science can not determine in advance.

Assume, however, that the engineering difficulties involved in the drainage of the works during construction, and those inseparable from the construction of a canal through the sickly bottom lands of the Chagres River—the damming off of its frightful floods, the creation of a new bed for its waters, and the deepening of the old one to constitute a part of the canal—can all be overcome by engineering skill, the question of expense still remains open and undecided; nor can it be fairly answered until the work has been completed. The cost of any work must always depend upon the number and character of the difficulties to be met and overcome; and the difficulties involved in the construction of a tide-level canal (only some of which I have mentioned) are of such a character that it is utterly impossible to fix with any degree of certainty the aggregate cost of the work. True, an estimate may be made, as indeed it has been by the engineers employed by M. de Lesseps. They have agreed upon the sum of $168,000,000 as the ultimate cost of the work, exclusive of interest during construction; but experience has shown that such estimates are quite unreliable, and are always much below the actual cost. I believe that the estimates for the construction of the Suez Canal were $40,000,000, while its actual cost was upwards of $90,000,000. It is not unlikely that upon the completion of the Panama Canal it would be found that the money expended was in amount twice as much as that estimated.

When the St. Louis Bridge was to be built, every system of bridge construction was examined to ascertain the cheapest method of building it, and various modifications of the plans were tried for the purpose of lessening its cost. A tunnel under the river was likewise considered. The result of all these studies was the erection of the present structure. The bridge proper, including the stone arches on each bank of the river, but exclusive of the tunnel and approaches, cost almost exactly $5,000,000, which was about twenty per cent. more than the estimate for it. The actual cost, however, was more than doubled by the items of interest, commission, discount, legal expenses, etc., which had to be paid. These items were omitted by M. de Lesseps, and formed no part of the estimate of the cost of his canal which he gave to the committee yesterday; and although they can not be properly said to be items of engineering, or even such as can be controlled by engineers, yet the fact is that they are insepar-

able from all great works. In the case of the St. Louis Bridge, the three first of these items alone cost the company $5,000,000, or as much as the entire cost of the bridge itself.

Another important question to consider in connection with this matter of expense, is that involved in the maintenance of the canal after it shall have been completed. Any one who contemplates the depth of the proposed cut through the several miles of the Cordilleras and thinks of the frightful rains and tempests which prevail during six months of the year, can form some faint conception, perhaps, of the amount of material which would be washed down the sides of this immense cut, as well as from all the other parts of the canal, and which must be continually dredged out of it, to preserve its usefulness.

The great delta at the lower end of the Chagres River is formed by the alluvions washed down from the high lands into the river. Its current has borne them out to the sea, where they have formed an immense deposit many miles in extent. Similar deposits must form in the canal from the same cause, but as it will be without sufficient current to sweep them out to the sea, they must be removed at great cost by artificial means. Experience in the maintenance of works constructed through districts visited by heavy rains proves that such maintenance is always attended with very large expenditures.

Should the canal ever be completed, with a cross section as small as that proposed, and which can not be increased except at enormous cost and the stoppage of its traffic during enlargement, it will not be practicable for large ships to move in it at a higher speed than two or two and a half miles per hour. Ships moving through narrow channels in a depth of water only a foot or two in excess of their draught are liable to take what pilots call "a sheer," or suddenly change their direction. They leave the shore which they are nearest to, and bring up against the opposite one before they can be controlled. In a narrow channel way, if the vessel be moving nearer to one bank than to the other, the water which flows from the stem of the ship to the side nearest the shore causes an elevation of the surface of the water on that side of the bow, greater than the surface of the water on the other bow. The keel being too close to the bottom to permit of an easy flow under it, and the water between the bow and the nearest shore being higher than that on the other side, the bow of the ship is forced away from that shore and brings up against the opposite bank. The more rapidly the ship is moving, the more likely is she to take "a sheer," and the more violent will be the contact with the bank. The day before my recent visit to the Suez Canal, a ship had been detained in it twenty-four hours, by getting aground in this way. It can be readily perceived that if the canal were cut through rock, such an accident would involve injury to the vessel. Through the alluvial portion of the canal a low rate of speed would also be

indispensable to prevent the injurious effect of the wash of the waves made by the ship.

While I have always been an advocate of those great public improvements which are necessary to meet the wants of commerce, I have constantly maintained that these great enterprises should be completed by the most economical methods known, and I think that an engineer would not be justified in advising the prosecution of a work involving very large expenditures of money, until he had satisfied himself that the results sought to be attained could not be as well secured in a less costly way.

If untrammeled by instructions from his employers, it would be the duty of an engineer, if charged with the solution of this Isthmian problem, to investigate every method by which this barrier to commerce can be overcome. Unfortunately, every expedition which has been sent out by this or any other government, or individual, so far as I have knowledge, looking to the transit of ships from ocean to ocean, has been instructed to find a practical route for *a canal*, and a canal only. Yet no intelligent engineer who will divest his mind of all prejudice, and take up the question of transporting ships over the Isthmus by railway, can fail to become convinced :

1st. That this method is entirely practicable.

2d. That upon any route where it is possible to build a canal it is equally possible to build and equip a substantial and durable ship railway for one-half the cost of a canal, if it be built with locks, and for one-quarter of its cost, if it be at tide level.

3d. That such a ship railway can be built in one-third or in one-quarter of the time needed for the construction of the canal.

4th. That when built, ships of maximum tonnage can be moved with safety at four or five times greater speed on the railway than in the canal.

5th. That a greater number of vessels per day can be transported on the railway than would be possible through the canal.

6th. That the capacity of the ship railway can be easily increased to meet the demands of commerce, without interruption to its business, whether it be to meet an increase in the size of the ships or in the number of them.

7th. That the cost of maintenance of the roadway and rolling stock will be much less than that of the maintenance of the canal.

8th. That the cost of maintaining and operating the railway, taken together, will be less than that of operating and maintaining the canal.

9th. That the railway can be located and successfully operated at localities where it is not practicable to construct a canal.

10th. That it is possible to estimate, with great accuracy, the cost of a ship railway, and the time needed to build it, because the work would be almost wholly upon the surface of the ground, whereas the

canal is strictly a hydraulic construction, involving control of water, and the execution of works under water or liable to be submerged or interrupted by water, thus rendering anything like an accurate estimate of the time and cost of its construction an impossibility. Hence capitalists,cannot know, with certainty, the amount of money and time required, or what the canal will probably pay when finally finished.

I am ready to establish the correctness of these propositions before the committee, and to answer any objections to them which may be urged by experts or others at any time.

My own studies have satisfied me that the largest loaded ships may be carried with perfect safety at ten or twelve miles per hour on steel rails weighing but seventy pounds per yard, the kind used on first-class railroads, and on wheels which shall not impose as great a pressure upon the rails as that of the driving wheels of a first-class locomotive when at rest; and that no grades need be encountered from ocean to ocean, on several routes, greater than one per cent., or 53 feet to the mile.

The application of the railway system to the transportation of ocean vessels promises more certainty of success than was given in favor of the application of steam on the ocean, before the passage of the Great Western from Liverpool to New York. The present proposition is not so much of an untried experiment as that was, because, to-day vessels of a few hundred tons burden are being transported by railroad both in this country and in Europe. Forty years ago large canal boats were, and I believe are yet, transported over the Alleghenies, in Pennsylvania, on the Portage Railway, and surely, with the wonderful achievements of the past forty years before us, no intelligent man will doubt that we can transport *ships to-day* by railway as easily as we could transport *canal boats forty years ago* by the same method.

Six years ago, when the question of opening the mouth of the Mississippi was being considered, the only means supposed by the great mass of the public to be possible was a canal, as in the present instance. It then required the utmost efforts and most persistent arguments to induce the Government to try the *cheaper* and *quicker* method of solving the difficulty by jetties. And so strong are prejudices fixed in the minds of men, that it is not at all unlikely that, if the jetty plan had not been backed up by my proposition to assume all the financial, and, I may add, the professional risk of failure, with the offer to do the work at less than the official estimates of its cost, the Government would to-day, and probably for ten years to come, be delving in the swamps of Louisiana to construct a canal at a cost three or four times greater than the jetties, which now maintain the deepest and safest entrance into any harbor from Maine to Mexico. Since the cheaper and quicker plan has been tried and found to be a success, it would no more be exchanged by the public for a canal than

they would exchange the magnificent ocean steamers of to-day for the clipper ships of the past. If their huge sails were seen alongside of the smoke-pipes of a White Star, a Cunard, or an Inman steamer, they would appear as absurd as the Fort St. Philip Canal scheme does when compared with the jetties of to-day. Is it not probable that the Isthmian canal schemes which are now absorbing so much of the time of the honorable committee, will appear equally absurd after the completion of a ship railway?

In conclusion, I beg to suggest that it is of the utmost importance to American commerce that it shall be enabled, when works upon the Isthmus are built, to receive all benefits and advantages therefrom at the least possible expense. It must be conceded that the capitalists, who will control the works when built, will be entitled to realize a profit proportioned to the magnitude of their investment, therefore it is a question of the first moment to the American people whether the necessary means cost $250,000,000 or only one-quarter of that amount.

Continuation of the Remarks of Mr. Eads before the House Select Committee on the Interoceanic Ship Canal.

Washington, D. C., March 9, 1880.

Allusion was made yesterday, by M. de Lesseps, to the effect of the tides at the mouth of the canal, and it was stated by him that, when the harbor in the Pacific should be deepened, the effect of the tides would be less felt at the canal entrance. This would be a result directly contrary to the laws that control the flow of water. The current is the result of the slope of the water's surface, and the retardation of the current is the result of friction at the bottom over which the water is moving. The friction of water in motion is much less, in proportion to volume, where the water is deep than where it is shallow. At the mouth of the St. Johns River, which I had occasion to examine with a view to its improvement, the tide, in deep water, on the coast, was 5½ feet; but on the inside of the bar, where the water was 12 feet only, the tide was but 4½ feet—a foot less—the difference being caused by the friction of the water in running in over the bar some three square miles in extent. The tides would rise still higher in the mouth of the canal, if the harbor were deepened in front of it. The tidal action would certainly be more energetic after such deepening, because the inflow would be more free, and it would rise higher. I was told by the manager of one of the steamship lines at Panama, a short time ago, that he had observed tides there 29 feet

in height. The effect of a tide even 14 feet would be vastly different from that of one of 4½ feet, such as occur at Suez. A tidal lock in the proposed canal would be, therefore, indispensable.

There is another matter to which I desire to call the attention of the committee. This is in reference to the drainage of the Chagres River as compared with the drainage of the Suez Canal. In the Suez Canal there was no drainage to look after. There were several lakes below the ocean level, through a portion of which the canal is constructed, and into these all drainage flowed naturally. But such is not the case at Panama, for there it will be necessary to build a dam which will cost $20,000,000 to restrain the water of one single river, and in addition, an immense drainage system will be needed during construction. The Suez Canal was nearly all made by dredge boats, working in the water. That, of course, would be practicable at Aspinwall through that portion of the canal which lies in the alluvial Delta of the Chagres, but the water must be kept out of the rock cutting through the remainder of the Isthmus.

SHIP RAILWAY.

I now propose to show to the committee, and will also be pleased to explain to Count de Lesseps, the plans for a ship railway which I have prepared.

Mr. Conger. Have you considered the question as to the feasibility of taking a vessel of middle age (one that is not entirely new and strong), of very large tonnage, over any railway without straining the vessel? Does your plan embrace the carrying safely of a vessel of any age and size without any liability to a strain?

Mr. Eads. Most assuredly. Any vessel that would, after inspection, be passed by the underwriters and authorities as capable of withstanding the gales and hurricanes of the Atlantic or Pacific Oceans, would be capable of being carried with absolute safety—with as much safety as a child in its mother's arms—across the Isthmus. My plan would not be practicable if it did not involve the ability to do that. In this connection I will state that I have had considerable experience in ship building myself, having constructed fourteen iron-clad vessels for the United States Government, among which were the first eight iron-clad vessels which the United States ever owned. These were built, and most of them had been in action, before the "Monitor" was launched. From the experience thus gained I can say with the utmost confidence that vessels can be carried upon the railway with perfect safety. I do not, however, stand alone in this opinion. The Hon. E. J. Reed, formerly Chief Constructor of the British navy, and perhaps the highest authority on ship-building in the world, has published a letter in the London *Times*, which has been

republished in this country, in which he indorses the project of a ship railway very fully and earnestly. The following is a copy of his letter:

"*To the London Times:*

"I write to express the hope that the project of substituting a ship railway across the Isthmus of Panama for the costly canal which is in contemplation, referred to in the letter of your Philadelphia correspondent in the *Times* of this day, will receive in this country and in France the consideration which it well deserves. I have for some time past had under consideration a similar scheme of my own for conveying ships across the north of the great peninsula of Florida, and although I have not had leisure to develop it sufficiently to justify me in putting it in detail before the pnblic, I have gone a long way toward satisfying myself that it is a feasible plan and highly economical in comparison with a ship canal.

"Mr. Eads, who has now announced and advocated the plan in America, is an engineer of the greatest ability, distinguished alike by the greatness of his engineering conceptions and by the theoretical and practical knowledge which he brings to bear upon their development. I first made his acquaintance in connection with war vessels and machinery constructed during the American war, and found him most able in grasping the essentials of the war-ship problem and in the application of steam to the objects in view. He has since given abundant evidence of engineering skill in other spheres and on larger scales.

"It may not be generally known that this country has done much in the way of lifting vessels bodily from one level to another, both in the case of the hydraulic docks of Mr. Edwin Clark and in the Anderton barge-lift in Cheshire, where the Bridgewater Canal and the River Weaver (of which the former is forty feet above the latter) are placed in working communication by the raising and lowering of pontoons with vessels afloat within them. I am satisfied that by modifying the plans of these hydraulic operations and greatly augmenting their scale, and by interposing railroad communication between the seas to be connected, ships can be conveyed across intervening land, and much less expensively than by canal, where the distance to be traversed is great. E. J. REED."

Mr. Henry Steers, I believe, is equally confident of the success of this method, as are also a great number of other eminent ship-builders and engineers of America and of England.

When I asked Mr. John Fowler (a very distinguished engineer who was employed by the late Khedive of Egypt at a salary of $40,000 a year) what he thought about a ship railway for the Isthmus of Panama, he said he could best answer that question by referring me to a report he had made on the Soudan Railway, where he proposed to carry steamboats around the first cataract of the Nile by the same method. I have not met an engineer who hesitates to say that the plan is practicable. When engineers come to investigate it and examine into the question of cost, they will see that it is far more economical than a canal. There cannot be a question about its practicability.

M. DE LESSEPS' COMMENTS ON MR. EADS' REMARKS.

M. de Lesseps said that he had listened to the remarks of Mr. Eads with respect, because he knew Mr. Eads to be an engineer who has done the most remarkable work of the day. He (M. de Lesseps) had noticed that sometimes the most eminent engineers studied the most difficult things. When he first spoke of actually cutting through the Isthmus of Suez, some of the great engineers then proposed to have a canal on a bridge instead of a cutting. It was necessary to distinguish entirely between the plan of a railway and the plan of a canal. He (M. de Lesseps) did not personally want to discuss the plan of a railway, because it was not his plan at all. A ship railway had never been tried, although it had been proposed. It had been proposed to him by Marshal Vaillant, war minister under Napoleon III. at the time that he was contemplating the cutting of the Suez Canal, but he did not want to look into it at that time, because if a thing of that kind was practicable, of course it could be done anywhere. A ship railway had nothing to do with the canal which he proposed to construct. He had noticed that Mr. Eads had criticised his figures as to the cost of the Panama Canal, implying that the estimates were less than the actual cost would be. These estimates had been made most carefully by the commission which met at the Isthmus, and of which Col. Totten and Mr. Dirks were two of the most prominent members. They had made every effort to have the estimates even higher than it was thought the actual cost would be, and his (M. de Lesseps') recent conversation with General Newton had confirmed him in the belief that the estimates were higher than the expenses would be.

In reply to Mr. Eads' remarks as to vessels stopping in the canal, he said that the only accident or real stoppage that ever took place in the Suez Canal was in the Bitter Lake, where the track is in the lake itself, and where sometimes vessels get out of the track and run aground; but he said that in the canal itself, if a vessel does touch one of the banks she is very soon got off, and does not interfere with the passage of other vessels. For eleven years that the Suez Canal has been open there has not been a single interruption in the transit of vessels. He hoped that in the Panama Canal the same system would be adopted as in the Suez Canal—never to have two vessels pass each other, and to have stations six or seven miles apart, between which communication is kept up by telegraph.

When Count de Lesseps had concluded, Mr. Eads said:

I am very much obliged to M. de Lesseps for the complimentary manner in which he has spoken of me. His opinion of me is, however, based on hearsay alone. My high respect for him has been formed after carefully inspecting the great work which has made

him so justly famous throughout the world; hence I have the positive assurance that my regard for him is well founded, and in this I have the advantage of him.

TEHUANTEPEC SHIP RAILWAY.

ADDRESS DELIVERED BEFORE THE SAN FRANCISCO CHAMBER OF COMMERCE, AUGUST 11, 1880.

Mr. President and Gentlemen:

I thank you for the opportunity which you have given me to address you. The question of the construction of a highway for commerce across the American Isthmus is one worthy of the attention of the people of the whole country, but to those of California it possesses a singular interest and importance. Any project which promises cheap and quick transportation for the products of your fertile soil, which holds out the hope of setting you free from the depressing effects of the high rates which you are compelled to pay upon all your exports, may well claim your most serious consideration. It is needless for me to dwell, however, upon the importance of this matter, for I know that I am addressing those who fully appreciate it. You have learned it from that best of teachers, experience. Year after year you have seen your broad acres yield the most abundant harvests. Blessed with a singularly genial climate and fruitful soil, a population active and energetic, a ready market for your grain in the East and a clamorous demand for it from the markets of Europe, it might well be supposed that your people were rapidly acquiring that wealth which is the legitimate fruit of their labors. Such, however, is far from being the case. Instead of being blessed with the prosperity which you should enjoy, there is on every hand evidence of depression. Of what value to you are your enormous crops, if the cost of transportation practically closes to them the markets of the world? Open up cheap water transportation, and all trouble is at an end. Then, and not until then, will you enjoy that prosperity which legitimately belongs to the development of your wonderful resources.

I am indebted to Capt. Merry for the following figures, as to the accuracy of which I have no doubt: It appears that last year the surplus of your wheat alone amounted to 600,000 tons, and it is estimated that this year the surplus will reach 800,000 tons. The average rate of freight around the Horn is $15 per ton, and, after careful investigation, it was found that such cargo could be transported by the Nicaraguan Canal at an aggregate cost of $10 per ton, thus saving upon the total annual shipment the large sum of nearly $4,000,000, or fifteen cents per bushel. This fact is something for the producers of California to ponder over. I am told by some of your intelligent citizens, who have doubtless thought but little upon the subject, that they have grave doubts as to the value of a ship transit across the Isthmus, because it would probably lose to San Francisco the trade of the Orient. But must this trade, which no doubt benefits this city to some extent, be enjoyed at the expense of the producers of the State? Must the farmers lose fifteen cents per bushel on their wheat, year after year, for the benefit that the arrival of an occasional shipload of tea gives to a few individuals in San Francisco? Must the wine-growers of the State have their profits continually discounted by the extra cost of carriage around Cape Horn, to retain a trade that must soon be shared by other ports on the Pacific that are the termini of other transcontinental roads? Will not the real interests of this city be more surely advanced by fostering the home industries of the great State of California? Fifteen cents per bushel saved to the farmer in transporting his wheat to a foreign market means fifteen cents added to his profit on each bushel of it shipped abroad. It means more than this. It means fifteen cents on every bushel of it that is consumed at home also, because that which is used in the State has its value fixed by that which is sold abroad. The same thing is true of the profits of the wine and wool-growers, the miner, and indeed every producer in the State who has to depend on a foreign market to purchase his surplus. In the four million dollars of annual saving to the State, to which I have alluded, reference is only made to your exports of wheat. If to this be added the increased value of that which is consumed in the State, and the savings on your other exports, the sum will be found great enough to pay for the cost of a ship railway, in four years, out of the benefits that will accrue to the people of this State alone. If we are answered that to raise the value of the wheat consumed in the State will make it cost more to the home consumers, I reply that the wine-grower, the miner, and other producers will enjoy like advantages with the farmer, because the ship transit across the Isthmus brings their productions ten thousand miles nearer to New York and seven thousand miles nearer to London, and this fact alone will add increased value to every acre in this State, and benefit every one who breathes the genial air of the Pacific Ocean.

In arriving at the estimate of $4,000,000, the tolls to be charged for passing through the canal were fixed at $2 per ton. Now, as the ship railway which I propose to construct will not cost more than half as much as the proposed canal, the tolls can be reduced in like proportion, and thus admit of an additional saving per annum to you on your wheat shipments of $800,000. If the railway were built at Tehuantepec, not only would you save in tolls, but there would be a saving in carrying distance over Nicaragua of seven or eight hundred miles, and a corresponding reduction in the freights. The surplus of which I have spoken is in wheat alone. I do not estimate the enormous crop of wool, wine, base ores, tallow, quicksilver, and other products which annually leave your shores for distant markets. The construction of the Nicaraguan Canal would require eight years; that of the ship railway would not exceed four years. Thus we find that the additional time consumed by the former in its construction would entail a loss upon you of the aggregate sum of about $20,000,000.

Several plans are proposed by which to secure a passage through or across the Isthmus for ocean vessels. M. de Lesseps urges a tide-level canal, Col. Menocal and his associates a canal with locks, while I am convinced that the only practical solution of the problem lies in the construction of a ship railway.

I am not insensible to the fact that the proposal to carry vessels with their cargoes upon a railway seems to many persons rather to be the wild dream of an enthusiast, than the sober, well-digested project of a practical engineer. When I approach the subject, therefore, I realize that there are many prejudices against it—prejudices which it is quite natural for any one, not an engineer, to entertain. I will, therefore, endeavor to explain, in as simple a way as possible, the plans which I propose, and I am convinced that when you fully understand them you will be satisfied that a ship railway is entirely practicable. When it was proposed, years ago, to apply steam to ocean vessels, the proposition met with any amount of ridicule, and he who made it was regarded as having lost his reason. Now the waters of every sea are plowed by the mighty steamers which have become the most reliable vehicles of commerce throughout the world. You will remember that when the proposal referred to was made, the propelling power of steam was a well-known fact, and its usefulness for certain purposes was admitted. The objection was that it could not be applied to ocean vessels, and there was no end to the reasons given in support of this objection. The most earnest opponents of this innovation upon established usage were found among ship-owners, captains, and sailors, who were all convinced that the application of steam to vessels would be the inauguration of an era of shipwreck and disaster greater than the world had ever before seen.

That era has not yet come, though I am not sure but that there are some who expect and wait for it yet.

The idea of transporting vessels upon a railway is by no means a novel one. Forty years ago this method was employed in transporting canal boats across the Alleghany Mountains in Pennsylvania. When it was found necessary to connect the eastern and western portions of the canal at Johnstown and Hollidaysburg, two methods presented themselves: one was to cut through the mountains and make the canal a continuous one; the other was to build a railway to carry the canal boats over the mountains from one portion of the canal to the other. Inasmuch as the railway was found to be incomparably cheaper, it was constructed and used until the Pennsylvania Railroad made it unnecessary. The railway thus used in connection with the canal was constructed in a very rude and primitive manner. It consisted of longitudinal pieces of wood, on which were placed rails of flat bar iron. This rude structure was found to be amply sufficient to admit of the safe passage of the boats. Now, just here I might ask, in passing, whether it does not seem reasonable, if, forty years ago, these canal boats could be thus safely carried over the Alleghany Mountains, that a railway can *now* be constructed which would with equal or greater certainty carry the largest vessels? He who is familiar with the wondrous improvements in everything connected with engineering in the last forty years would scarcely answer this question in the negative. There is in operation at present, within a few miles of Washington, a railway upon which canal boats, heavily laden with their cargoes, are daily transported up a steep grade from the Potomac River to the canal above. In Europe I know of two railways of a similar character now in operation. Surely, if a railway can be constructed of sufficient strength to carry a canal boat, there is no reason why one could not be constructed strong enough to carry an ocean vessel. The whole question is one of force, and whenever an engineer can bring a problem down to this, its solution is an easy one.

In the construction of a ship railway, of course, the whole work would have to be upon a very large scale. The road-bed must be a solid one, and all machinery employed of a character consistent with the great weight of the vessels to be transported. I propose to employ, instead of two rails, as in ordinary railways, not less than twelve rails, and under each car to place a multitude of wheels. In this way the pressure upon the rails would be so distributed that at no point would it equal that imposed by an ordinary first-class freight engine while at rest.

One of the first objections presented to the mind by this plan is the great weight to be borne by the road-bed. A cradle for a ship and cargo weighing six thousand tons would be about 350 feet long, and would rest on 12 rails spaced 4 feet apart; hence we would have a

bearing 44 feet wide by 350 long, which is 15,400 square feet. This is equal to 780 pounds only on each square foot of the road-bed. A brick wall 8 feet high will give the same pressure. Surely, when we look at the stately houses built on the mud flats which you have reclaimed from your magnificent bay, you cannot doubt the ability of the solid earth, on which the ship railway would be built, to sustain the largest ships in transit. If you will observe the slight tracks made by the shoes of a good-sized trotter on one of your dirt roads, and compute the pressure of the horse upon the earth, you will find it is nearly or quite eight times as great per square foot as our ship railway would impose. The weight of the horse is alternately borne upon two feet only while trotting. If we assume the area of each shoe to be 12 inches, the weight of the animal must rest at each step upon but 24 square inches of earth, or the sixth part of one square foot. If we assume the weight of the horse to be 1,000 pounds, he would press the earth at each step with nearly eight times as much force per square foot as the largest ship on our railway; and yet his great pressure leaves scarcely an imprint of the shoe, although to the weight of the horse there is to be added the force or sudden blow with which the animal strikes the earth.

On each of the twelve rails, under a cradle 350 feet long, we would have 115 wheels. Each rail would then carry one-twelfth of the six thousand tons, or 500 tons. This would be about 4 tons and one-third on each wheel. As the drivers of a large freight engine at rest give a pressure of over six tons each upon the rail, it will be seen that we really need no heavier rails and ties than are used on first-class railways. With the pressure of the ship thus distributed, it is plain that she cannot bend, twist or strain in any way, unless the earth gives way under her, and this is not likely to occur if ordinary care be used in building and maintaining the road-bed. It may be said that the rails cannot all be kept perfectly level. This is true to a certain extent, but an inequality of one inch in them could only occur as a result of negligence; but, to remedy any possible unevenness in the rails, each wheel would have over it a strong spiral steel spring that would admit of several inches of play.

To avoid bending the ship in changing from one grade to another, the cradle could, if necessary, be run on to what may be called a tipping table, placed in the line of the railway. This would rest on a fulcrum at the middle and on hydraulic rams at each end, so that the ends could be raised or lowered to conform to the different grades. To avoid curves in the railway, turntables long enough to receive the cradle would be placed at necessary points in the main track, and on these the cradle would be turned to the right or left, to change the direction of the ship. People who think it impracticable to carry a loaded ship in this way with perfect safety, know but little of the immense resources which the science of mechanics gives to an engi-

neer. There are many ways by which a vessel may be supported, with absolute safety to ship and cargo, when out of the water. It has been suggested that the ship should be carried in a tank of water; but if the ship is not strong enough to be carried with her cargo on a dock out of water, on a smooth railway, when she has been built to buffet the hurricanes of the ocean, do we lessen the difficully by building a second vessel in which to float the first one, which must not only be strong enough to carry the ship and her load, but a mobile cargo of water weighing half as much more? To carry the ship in a tank of water would convert an imaginary difficulty into a real one, and besides adding to the cost of the railway, would impose upon it a vast amount of unprofitable cargo.

In the case of the ordinary freight cars upon our railways, you have observed that the trucks are placed at each end of the car, and thus that part of the rails where the wheels are placed, alone bears the whole weight of the load, while that portion of them between the trucks is doing no service at all. This method of constructing cars is necessary where there are curves upon the road, but as the road which I propose to construct across the Isthmus will be free from curves, the wheels may be placed at very short distances apart under the whole body of the car, and thus the great weight be distributed. With a sufficient number of tracks and wheels, there will be such a distribution of the weight that the largest vessels afloat can be carried without imposing any greater burthen upon the rail at any given point than that imposed a hundred times a day upon the rails of every first-class road in the country.

Each wheel will be separate from the others, so that, in case of breakage, any wheel can be taken out without affecting the others. The strength of one or two wheels, or that of a dozen of them, is so insignificant when compared with the whole number, that derailment of the car would be almost impossible.

The cradle upon which the vessel will rest, may be compared with a dry-dock. The only real difference between it and an ordinary dry-dock is, that the former is stationary, while this one is placed upon wheels. This cradle or dock upon wheels will be backed down upon the railway, on a grade of about one foot in 100, until it reaches a sufficient depth of water to enable the vessel to be floated upon it. When the ship is in position, she will be safely secured over the cradle and then the car will be slowly drawn forward. As the water becomes more shallow, the vessel will naturally take her position upon the cradle; the supports will then be moved up against her hull, while still afloat, so that she cannot move on the cradle, and she will then be drawn up the incline until she reaches the level track above. Here two powerful engines will be attached, and the vessel will be at once started upon her journey across the Isthmus. At the end of her jour-

ney she will be put into the water in the same manner that she was taken out.

I think that I have said enough to satisfy you that this plan is a very simple one, and entirely practicable. I have shown you that the question is one in which every element can be accurately calculated. That the distribution of weight affords an ample guarantee that the road-bed will be strong enough to bear the burthens imposed upon it, and surely no one will doubt that if an ordinary dock can be built strong enough to support a large vessel, a dry-dock of equal or greater strength can be constructed which may be moved with facility on wheels. There is scarcely any limit to the power which may be employed.

But at this point I will pause for a moment to notice a difficulty which no doubt presents itself to the minds of many of those who hear me. Probably you will all at once concede that the construction of the railroad is practicable, and that vessels, however great their tonnage, can be carried upon it; but you doubt whether it would be possible to carry a vessel upon the railway without straining or otherwise injuring her. I have found that this objection is urged with great pertinacity by many of those who are most interested in seeing the isthmian barrier removed; and therefore, while I know that the fear is groundless, I am prepared to respect the opinions of those by whom it is entertained, and concede to them the very best of motives. I call your attention to the fact that the objection referred to is urged, not by educated engineers, but mainly, if not entirely, by non-experts. Now this is not the way in which you reason, my doubting friends, in the ordinary matters of every-day life. If you have a business complication requiring professional advice, you seek a lawyer in whom you have confidence, and follow his counsel. If you find it necessary to employ the services of a physician, you accept what he says as verity, and, never doubting, obey his instructions; and yet, when the most cultivated men in their profession declare in the most emphatic terms that a ship can be safely carried by rail, you are unwilling to accept their decision. Some of the ablest engineers in this country and abroad have declared unhesitatingly that loaded vessels may be thus carried in perfect safety. Among those who have so declared is Hon. E. J. Reed, late Chief Constructor of the British Navy, an engineer of the highest reputation, whose knowledge and experience in ship-building are second, perhaps, to that of no man living. Indeed, I may safely assure you that since I first broached the subject of a ship railway, I have not found a single engineer who has expressed a doubt as to the practicability of the project. Does it not seem reasonable, then, that you should accept the views of those who are best able to decide these questions, and who would be unwilling to hazard their reputation upon a decision where the least tangible doubt existed as to the correctness of their views?

Those who are most persistent in the belief that a vessel in transitu upon the railway would be strained or burst asunder by the weight of her cargo pressing against her sides, are controlled, not by reason, but (unconsciously, no doubt) by prejudice. They imagine that when in its element a vessel has the pressure of the water constantly outside, to counteract that of her cargo within. In this they are mistaken. In stormy weather and in a rough sea there are times when every part of the vessel is exposed to a strain far greater than it is possible to subject her to on a ship railway. There are times, too, when the resistance of the water is almost wholly withdrawn from different parts of the ship.

In crossing on the "Scotia," in heavy weather, I saw one wheel frequently out of the water high enough to drive a horse and cart under it. Of course, a great deal of support was taken away then from the ship's centre. At another instant the huge wheels would be almost wholly submerged and the bow and stern be high in the air. Then, as the ship passed over the crest of that wave, the stern would rise higher still, while the bow would plunge downwards through the trough and rush so deeply into the next wave that no one could stand on the deck at that end of the ship. At the next instant the bow would be uplifted high on the second wave, while the stern would sink almost out of sight down in the trough of the sea. It is not possible to strain a vessel thus severely on a ship railway. If she be bent at all in the direction in which she is most easily bent, longitudinally, she has got to bend the earth itself under her.

A loaded vessel that could not ride with safety upon the proposed railway is unseaworthy, and wholly unfit to be trusted with either life or property. But it must be remembered that, should it be necessary to give any additional strength to the sides of the vessel, almost any number of supports may be employed. These can be made to extend from the sides or galleries of the cradle, and could be so applied that injury to the vessel would be simply impossible. In this connection I may add that it is by no means an uncommon thing to place a vessel, loaded with her cargo, upon a dry dock for repairs. Quite recently the "Goethe," one of the large steamers belonging to one of the German lines, was placed with her full cargo upon the New York dry dock, where she remained for a number of days. In England the same thing has been done with other large steamers. If no injury results to vessels thus handled, it would seem that their safety upon the movable cradle or dock of a ship railway should not be doubted.

But suppose a canal be constructed, is there no danger of injury to vessels passing through it? I do not know of a single route across the Isthmus where it would not be necessary in the construction of a canal to cut rock to a greater or less extent. In passing through

these cuts there would always be danger to the vessel. Were she to take a sheer at such a place, and were she to be carelessly handled, she could not fail to be injured. But, say some, danger from contact with the rock sides can be averted by the use of floating fenders of wood placed at the sides of the canal. True, but all these appliances involve large expense in their purchase and repair, and increase the estimated cost of the canal and its maintenance.

Another and perhaps the leading objection to the canal is its locks. Commerce demands a removal of all barriers, natural or artificial, so far as practicable. Here would be the removal of a natural and the substitution of an artificial barrier. A canal with its numerous locks would be a constant menace to your commerce. An injury to any one lock renders the whole work useless until it is repaired. Experience has shown that a navigation dependent upon locks, whether in slack water or canal, is hampered by many delays, while the expense involved in the necessary repairs of the work is a constant tax upon the commerce passing through it. Another strong objection to the canal is that when constructed it cannot be enlarged to meet the wants of increasing commerce without an expense so great as to practically preclude any effort in that direction. This is a very important consideration. A canal so constructed as to meet the wants of present commerce might be wholly inadequate to accommodate the ships of ten years hence. The tendency of the day is to increase the size and tonnage of vessels, and who can tell what the ships of the future may be? There are a number of canals, constructed years ago, and thought at the time to be of ample proportions, which are now almost abandoned or nearly useless. But it is said: "Construct the canal in such a manner as to leave an abundant margin for the increased size of vessels." This, of course, could be done, but the increase in size means an increase in cost, largely in excess of the amount estimated. Just in proportion as you increase the cost of the work, just in such proportion do you increase the tolls and charges which will be imposed upon your commerce. These tolls and charges must, of necessity, have relation to and be regulated by the aggregate amount invested in the construction. You must never lose sight of the fact that the great object which you are seeking is to secure cheap transportation for your products. Here is just the weak point in M. de Lesseps' scheme. That a tide-level canal could be constructed at Panama no engineer seriously doubts, but it is very certain that such a work would cost from three to four hundred million dollars, and that the cost of maintaining it would be beyond all reasonable estimate. Were you to adopt this as a means of escape from the evils which you now endure, you would soon realize that you were in the position of the doves which, through fear of the kite, sought the protection of the hawk. This question of the cost and maintenance of any work constructed upon the Isthmus is a vital

one, and should go very far toward influencing you in the conclusions which you reach.

In the very able report upon the Nicaraguan Canal, recently made to your Chamber of Commerce, it is estimated that eight per cent. per annum could be realized by the company, and the tolls not exceed two dollars per ton. This estimate is based upon $100,000,000, as the aggregate cost of the work, which sum is less than one-third of that required to build the tide-level canal proposed by M. de Lesseps. The annual tonnage to be carried is placed in this report at one million tons below that estimated by De Lesseps (namely, at only 5,000,600 tons). Now, if the Nicaraguan Canal Company can pay an eight per cent. dividend annually by the imposition of a toll of but two dollars per ton, the same dividend can be declared by the ship railway upon the imposition of a toll of but one dollar per ton, for the reason that the cost of the ship railway will not exceed fifty millions of dollars, or one-half the sum required for the construction of the canal; nor will its maintenance and operating expenses be in any greater proportion.

I am convinced that the estimate of the cost of constructing the canal at Nicaragua is far below what it will actually cost, and that it cannot possibly be built as proposed for less than $100,000,000. Should the proposed work be constructed, it will be found that the cost of improving the harbor at Greytown will far exceed any figure which the sanguine advocates of the scheme are now willing to place upon it. The cost of maintaining its harbors when improved, that of dredging the canal and keeping it and its locks in repair, and a hundred other minor expenses, demand the attention of those by whose products and labor the necessary interest on the capital invested must be paid.

Standing in your presence to-day, and conscious of the full import of my words, I declare to you—

1. That a ship railway can be constructed at one-half the cost of a canal with locks, and in one-half the time.

2. That when completed, the railway can be maintained and operated at a cost not exceeding that of a canal.

3. That your largest vessels, with their cargoes, can be safely carried from ocean to ocean in one-half the time required for a passage through the canal.

These considerations alone, it seems to me, should decide you at once in favor of the railway. But these are not the only ones. The railroad, when completed, can be enlarged from time to time as the wants of commerce may demand. And should the commerce using the road demand a double instead of a single line of tracks, the work can be speedily done and at a reasonable expense, and without interfering with its traffic. Another matter which I desire to suggest is this: Wherever a canal is practicable, a railway is also practicable;

and at some points a railway could be constructed where a canal would be out of the question. As you reduce the distance for the carrying of your freight you reduce the cost of transportation. There can be no doubt a ship railway could be constructed at Tehuantepec, and if this route were selected almost seven hundred miles of transportation would be saved over that necessary if the transit was by Nicaragua.

But I have already trespassed too long upon your attention, and will draw my remarks to a close. The opportunity is now afforded you to have a work constructed which will strike the shackles from your commerce and contribute wealth and happiness to your people. When I proposed, years ago, to give to New Orleans and the Mississippi Valley a safe and deep outlet to the Gulf, and assured the people that I was able soon to remove the barrier which barred the entrance to their mighty river, I was met with the same old cry of "Canal!" "Give us a canal!" said they; "that is the only relief from our troubles; a canal and happiness are synonymous terms." When I pressed upon Congress and the people my project for improving the mouth of the river by the application of the jetty system, a resolution was actually passed by the New Orleans Chamber of Commerce recommending the construction of a canal from Fort St. Philip to the Gulf, and a letter, earnestly requesting me to cease further effort in behalf of the jetties, was addressed to me by a large number of the merchants of that city. Convinced that these people were misguided and blind to their own best interests, I heeded not their requests, but pressed my project with redoubled zeal until success attended my efforts, and the work was intrusted by Congress to me. To-day the Mississippi River is open to the largest ship that floats, and all of the business interests of New Orleans cursed as they were with stagnation and decay, have been inspired with energy and blest with new life. To the producers, the merchants, the business men of this great State are now offered like benefits. It remains to be seen whether my efforts will be hampered by your opposition or encouraged by your aid and influence.

THE ISTHMIAN SHIP RAILWAY.

[From the North American Review, March, 1881.]

The question of a transit for ocean vessels through the American Isthmus has occupied the attention of the civilized world for the last three hundred and fifty years. The great benefits which such a work would confer upon commerce were fully recognized even in the days of Cortez, and each year since has increased its necessity. The question naturally arises, Why has this great work been so long delayed? The answer lies in the fact that the majority of mankind cling to old methods rather than adopt new ones, even when the old ones are far more expensive and less efficient. It matters not that the untried ones rest upon the most evident deductions which can be drawn from scientific research or undisputed facts. Until they are demonstrated by actual test, those who propose them are looked upon as visionary enthusiasts. The opposition to the introduction of the steam engine, steam loom, steamboat, locomotive, and electric telegraph furnishes abundant evidence of the hesitancy and reluctance with which even the most intelligent communities adopt new methods.

For over forty years, futile efforts were made to deepen the mouth of the Mississippi by the antiquated means of dredge boats. When these were found inadequate, the only solution deemed possible was the still more ancient and expensive one of a canal, to be cut through the eastern bank of the river to the Gulf.

A proposition to deepen one of the mouths of the river, by concentrating the force of the stream itself upon the bar, was ridiculed and pronounced impracticable by professional gentlemen of the highest respectability, and nothing but the offer to guarantee the absolute success of the plan was sufficient to induce the Government to abandon the idea of a canal. In fact, $8,000,000 with which to commence the canal was voted by one branch of Congress, after this offer was made. But it was not until a second commission of engineers was authorized to investigate the merits of the jetty system, that the proposition to attempt the experiment, even at the sole cost and risk of a few private individuals, was sanctioned by the Government.

At the congress of distinguished engineers from all parts of the world, assembled in Paris in 1878, at the instance of Count de Lesseps, to investigate the question of interoceanic transit across the American Isthmus, the only plan considered was that of a canal, and

the decision was that the problem should be solved by a sea-level one at Panama. Its cost was estimated at twelve hundred million francs, or about two hundred and forty million dollars. Subsequently, more careful estimates reduced this amount to $168,000,000, without including interest during construction.

In a locality where for six months in the year the rainfall is incessant and enormous, it is not probable that such a work can be completed in less than twenty years. But if we assume that it can be done in ten, the interest at five per centum during this time would add $84,000,000 to this estimate, making a grand total of $252,000,000.

In the last half century science has made such marvelous advances that, in the department of mechanics, it has placed resources within the reach of the engineer which were totally beyond his grasp before, and it is now an axiom of the profession that all things are possible, if the necessary money to execute them be provided. Therefore, a sea-level canal across the Isthmus of Panama is not an impossibility.

The immense rainfall, and the unhealthfulness of the climate, will interpose the greatest obstacles to the work. So long as the bottom of the canal is kept above the ocean level, the engineer will require only such drainage works and pumping apparatus as are necessary to remove annually water sufficient to cover, to the depth of about thirteen feet, the entire area drained by the canal. But, knowing the average rainfall, he will be able to provide means for its removal from his excavations. When, however, the ocean itself is tapped, as it must be in cutting the canal twenty-eight feet below its surface, ordinary methods of drainage become impossible, and the quantity of water which will probably enter through veins and fissures below the ocean level is an unknown quantity, which engineering science can not determine in advance. Yet even this formidable difficulty may be overcome, if the additional amount of money be provided. The success which has attended the recent subscription to this enterprise seems to prove that there are many people ready to invest their money, on condition that they get five per cent. of it back every year during the time the canal is building, as is promised by the Universal Interoceanic Canal Company. As sixty million dollars are already subscribed to start the canal, on these terms, we may fairly conclude that subsequent subscriptions will be sufficient, if judiciously used, not only to pay back five per centum of it annually, and to manage the rainfall, but also to pump out such part of the ocean as may intrude itself into the works during construction. Annoying delays to commerce may arise from these extraordinary difficulties, but the fact that the shareholders have a five per cent. dividend-paying stock, tolls or no tolls, will stimulate new subscriptions until the canal is completed, or until this novel method of raising money fails.

Of the commerce which will pay the tolls of any transit route for

ships across the Isthmus, three-quarters will probably be American, and as the charges will doubtless be in proportion to the cost of the works, it is a matter of prime importance to the commercial interests of the United States to secure the construction of them for the least practicable sum.

The total amount of this traffic has been estimated by the Chief of the Bureau of Statistics, Mr. Nimmo, to be at present only one million six hundred and twenty-five thousand tons annually. The Panama projectors estimate it at six million tons.

Although the estimate of Mr. Nimmo may be fairly criticized for the exclusion of a large amount of tonnage which he assumes will continue to go around the Horn to the eastward, it is probable that the real amount which the line will receive when opened will not exceed three million tons per annum. It is not likely, therefore, that the tonnage crossing the Isthmus within the next generation will support more than one line of ship transit across it; and if we are to have moderate tolls, it is imperative that the transit be established upon that part of the Isthmus which will secure the shortest routes for our foreign and coast trade, because every additional mile which the vessel must travel would inevitably add to the cost of transporting the cargo it carries, no matter whether the increased cost results from higher tolls or a longer route.

Many persons will be surprised to learn that the isthmus which connects North and South America is as long as the distance between New York City and the mouth of the Sabine River in Texas.

Panama is located near South America, and its distance from Tehuantepec, in Mexico, is 1,250 statute miles. Any vessel leaving New York for San Francisco, China, or Japan must have at least that much additional distance added to her passage in the Pacific, as well as an additional distance in the Caribbean Sea, if she crosses at Panama instead of Tehuantepec, as the Isthmus lies nearly parallel with the route she must traverse. A steamship from New York or Charleston must travel 1,500 miles further to reach her destination than she would if she could cross the Mexican Isthmus. The cargo which leaves San Francisco for Europe must run the length of the whole Isthmus, and thus be delayed six or seven days more than it would be if it crossed at Tehuantepec. Nor can these great delays be saved by the proposed canal at Nicaragua. It will be about twice as long as the Suez Canal, and steamships require two days in passing through the latter, although it has no locks. It is fair, therefore, to infer that thrice as much time would be consumed at Nicaragua, inasmuch as a canal there must have numerous locks. Any attempt to pass these locks rapidly will involve great danger to the lock gates, and an injury of that kind may require weeks of delay for repairs. No advantage can, therefore, be claimed for the Nicaragua route over that of Panama, for the canal proposed at the latter

place is but forty-five miles long, and without locks. A passage through it could be made in one day, while at Nicaragua the crossing would probably require five or six days.

The valley of the Mississippi, so wonderfully productive, with its marvelous network of rivers ramifying through every portion of a territory larger than the combined areas of Germany, Austria, France, Spain, Italy, Great Britain, and the Netherlands, and capable of supporting, if peopled as densely as Holland, at least four hundred million souls, has but one natural outlet for its enormous productions—the mouth of its great river. The commerce of this immense region, if it seek a passage to the Orient or California by the Panama Canal, must be diverted out of its direct course a distance almost double the length of the Isthmus. It must travel 2,200 miles further to reach those markets than by way of Tehuantepec. These distances are but faintly realized when thus stated, but when the map is measured, and we find that a ship from New Orleans to San Francisco, instead of crossing at Tehuantepec, must go as much farther by the way of Panama as it is from New York City to the eastern boundary of Oregon, every intelligent American must condemn the policy of permitting the transit to be made where it is so manifestly against the commercial interests of his country.

In speaking of the difference in distance by these several routes, reference has been had only to steamships. Upon this subject, Capt. Silas Bent, a gentleman who has devoted much study to the winds and currents of the ocean, and who was formerly an officer of the United States Navy, made the following statement a few days ago before the Merchants' Exchange at St. Louis:

"Mere statements of the difference in miles is a very inadequate measure of the difference in time that would be occupied by sailing vessels in making these several passages, and when we consider that three-fourths of the ocean commerce of the world is carried in sailing vessels, you can see what an important factor this question of *sailing time* becomes in the solution of the problem before us.

"The northeast trade winds which extend across the Atlantic are so broken and interrupted when they encounter the West India Islands, that they never penetrate the Caribbean Sea; but the northwest portion of them, however, do extend into the Gulf of Mexico, and often so far down as to reach well toward Tehuantepec, so that whilst in the Gulf winds are always found, yet the Caribbean Sea remains a region of almost relentless calms.

"Nor is this all, for the mountain ranges, extending the length of the Isthmus of Panama and through Central America, offer a still more formidable barrier to the passage of these winds, thus throwing them still higher into the upper regions of the atmosphere, and extending these calms far out into the Pacific Ocean, on the parallel of Panama, with lessening width, for fifteen or eighteen hundred miles to the northwest, along the coast of Central America.

"This whole region of calms, both in the Caribbean Sea and in the Pacific Ocean, is so well known to navigators that sailing vessels always shun it, if possible, though they may have to run a thousand miles out of their way to do so.

"This absence of wind, of course, leaves this vast area exposed to the unmitigated heat of a torrid sun, except when relieved momentarily by harassing squalls in the dry season, and by the deluging rainfalls of the wet season. With these meteorological facts in view, let us now suppose that the De Lesseps Canal at Panama, and the Eads Railway at Tehuantepec, were both completed and in running order; then let us start two sailing ships of equal tonnage and equal speed from the mouth of the Mississippi, with cargo for China, one to go by the way of the Panama Canal, and the other by the way of the Tehuantepec Railway, and I venture to affirm that by the time the Panama vessel has cleared the canal and floats in the waters of the Pacific, the Tehuantepec vessel will have scaled the Isthmus and be well on to the meridian of the Sandwich Islands; and that before the former vessel can worry through the fifteen or more hundred miles of windless ocean before her, to reach the trade winds to the westward of Tehuantepec, the latter will have sped five thousand miles on her way across the Pacific, and be fully thirty days ahead of her adversary. For it is a fact worth mentioning here, that the strength of the northeast trade winds in the Pacific, as well as the maximum strength of the northern portion of the great equatorial current in that ocean, are both found on or near the parallel of latitude of Tehuantepec, the former blowing with an impelling force to the westward of ten or twelve miles an hour, and the latter with a following strength of three or four miles per hour."

In considering this important question from a military point of view, the superior advantages possessed by Tehuantepec over Panama and Nicaragua will be apparent to any one who will examine the map. A few iron-clads and torpedoes placed in the narrow channel between Yucatan and Cuba, and as many more in the Florida channel, would defend the entire Gulf of Mexico against almost any naval force that could be concentrated in them; while it would be simply impossible to isolate as completely the Caribbean Sea with ten times as many iron-clads. It would be almost impossible for the United States to hold the Panama or Nicaraguan canal against such a naval force as either France or England, with its present navy, could bring to bear against it.

Two very important railroads are now being rapidly constructed in Mexico by American companies; one extending from Texas, and the other from New Mexico, to the City of Mexico. A very superior railroad is already built from the City of Mexico to Vera Cruz. This latter city is only one hundred and nine miles from the mouth of the Coatzacoalcos River, which will be the entrance to the ship railway. A railroad from Vera Cruz toward the mouth of the Coatzacoalcos has already been commenced. By these railroad lines a very large body of troops could be rapidly concentrated in Tehuantepec, to protect the works against a hostile land attack. The gulf end of the railway would be at least thirty miles in a direct line from the gulf coast, and the Pacific terminus of the road would be fourteen or fifteen miles from the Pacific coast. Both ends of the road would, therefore, be beyond the reach of the guns of an enemy's ship, unless it

entered through the Coatzacoalcos River or the jettied channel of the lagoon on the Pacific side—both of which channels could be easily and cheaply defended by torpedoes. In addition to this, the ship railway would be located on the territory of a powerful and friendly republic, whose history has not only proved its aversion to European domination, but has shown its power to deal successfully with an invasion of its territory. We have, therefore, the assurance that Mexico itself is able to protect, very effectually, the ship railway, without the aid of any other power. On the other hand, we have no assurance that the interests of the small and much less powerful States of Nicaragua and Columbia would not be enlisted in favor of European intervention. It is not many years since a convention was concluded between France, England and Nicaragua, by which the integrity of Nicaragua was guaranteed by its two powerful allies.

It would be idle to undertake to defend a canal at Nicaragua or at Panama with American troops, becaase of the difficulty of sending them overland to either point, and of maintaining them in such an unhealthy region, and so far from any available base of supplies. This difficulty would be greatly enhanced if it should happen that the citizens of either country favored such European intervention as the United States would feel compelled to oppose.

If *a canal* were equally practicable at Tehuantepec, no intelligent American would hesitate a moment to give it the preference over any other route. But, are the immense natural advantages of that location to be disregarded because a canal cannot be used, when the most eminent ship-builders and many of the ablest engineers in the world do not hesitate to declare in print, over their own signatures, that a ship railway is not only practicable, but that it is really better than a canal?—that it is much cheaper to build; that it can be more quickly constructed; that the largest ships can be transported much more rapidly, and with equal safety on it; that it can be more easily enlarged to meet the future demands of commerce, and that its maintenance will be less costly?

But, say some, "You cannot transport ships by rail without straining them. It is impossible to take a laden ship out and put it upon a dry dock without removing her cargo. It will burst her sides out, and she will be bent and strained while in transit over the railway." These objections are advanced by men who have not studied the principles of ship-building or engineering, and who are therefore not competent to form a correct judgment on the subject. The captain of an ocean steamer, and the engineer who plans and builds her, follow professions that are widely different. The engineer would be as unfitted to command and navigate the ship as the captain would be to deal with the mathematical processes by which the materials in her hull and engines are proportioned to bear the various strains which each particular part must resist. Men who are competent to

investigate and determine the infinite variety of strains which the boilers, engines, propeller, shaft, and various parts of the ship must bear, while the vessel is plunging, twisting, and bending under the fury of a storm, are certainly competent to pronounce upon the practicability of transporting her upon a well-built railway. There is no lack of testimony from men of this kind in favor of it. But the transportation of vessels upon a railway is by no means an untried experiment, and therefore it is not wholly dependent upon the opinion of experts.

Within four miles of Washington, a railway, composed of four rails, transports canal-boats from the Potomac River to a canal which is about thirty feet above it. The boats are conveyed over the railway several hundred feet to the other level. The total load each trip weighs about three hundred tons. The canal-boats are carried in a tank of water* about seven feet deep, yet the water does not burst out the sides of the tank, although there are no beams across the top of it to tie its sides together. Ships have their sides strongly tied together by their deck-beams, and they are rarely more than seven feet between decks. There is no cargo which will tend to burst out the sides of a ship more than that of grain in bulk, and grain is not as heavy as water. Consequently the ship's sides have the advantage of the canal-boat tank in the fact that they are strongly bound together by the deck-beams, whilst the tank has nothing at all comparable in strength to sustain its sides. There is no sea-worthy iron or wooden vessel afloat upon the ocean whose sides are not sufficiently strong to resist bursting, if the vessel were put in a dry-dock and filled with water to her main deck, and this would be a much greater internal pressure than any cargo could create.

If it be supposed that the ship will be bent in the direction of her length, we have only to inquire into the pressure which the vessel and car impose upon the road-bed to have such fear banished at once. Trains of one thousand tons weight are not uncommon upon ordinary railways. I have been assured by a gentleman of great experience in railway management that he has seen a freight engine, of the Mogul pattern, haul one train of eleven hundred tons on the Illinois Central Railroad. If six such trains were placed side by side, they would represent the weight of one of the very largest steamers when loaded. There would be no fear of the ground giving way beneath these six trains, although a large portion of the earth under them would sustain no portion of the load when at rest, because each end of an American railway car rests on a truck with four wheels, while fifteen or twenty feet of the road under the middle of each car has no load whatever upon it. No wheels are placed under this part, as

* I do not approve of the plan of carrying vessels in tanks of water, over long distances, as it involves the cost of carrying a great weight without compensation.

they would interfere with the passage of the car around curves; but as the ship-railway will be absolutely straight, the wheels can be placed as close together under the ship as they are at each end of the car.

In the ship-railway cars the wheels will be two feet in diameter, and will be placed three feet apart on the rails. It must be evident that if we place as many wheels under the ship as are required in the six railway trains just referred to, the ship may be of a weight equal to them, without imposing any more pressure upon the rails at each point of contact than is imposed upon the wheels supporting the six railway trains. The pressure of the driving-wheels of a locomotive at rest is about six and one-half tons for each wheel. The pressure on the ship-railway will be limited to five tons per wheel. The rails and wheels will, however, be quite capable of bearing twenty tons on each wheel, and, to provide for any inequality in the rails, steel springs will be placed over each wheel. As each one of these wheels will have an independent axle, and be disconnected from any other, the derailment of the car will be almost impossible. An additional safeguard against derailment will be found in the slow rate of speed (eight or ten miles an hour), and in the fact that each division of the road will be straight. Turn-tables, long enough to carry the ship and car, will be placed where a change of direction in the road becomes necessary. By this means the car and its burden may be turned to correspond with another straight reach of track. From the surveys thus far made, it is not anticipated that more than three of such turn-tables will be required on the entire line of road.

A misapprehension exists regarding the danger of bending the ship where a change of grade becomes necessary. At Tehuantepec, one foot in one hundred will be the maximum. From a horizontal plane to this grade, the change can be made so gradual in the distance of one mile, that a ship four hundred feet long would not be bent one inch out of a straight line if it conformed to the vertical curvature of the track. But the springs under the car will prevent even this little bending.

It is not generally known that all materials used in the construction of ships are elastic, and that large iron vessels bend and twist during storms to an extent that seems impossible. No iron bridges are so constructed but that the elasticity of the iron permits them to bend under the weight of an ordinary freight train. Spans of four hundred feet, when tested with heavy loads, usually bend from four to five inches, and a ship of that length will bend quite as much without injury. Wood being more elastic than iron will bend much more. Those who have crossed the Atlantic have not failed to hear the creaking of the cabins during storms. This could not occur if the hull did not bend and twist to some extent. The fear of a ship being strained while in transit is founded in a want of knowledge of the

strength of ships, and of the capability of the earth to sustain the load. Fifteen hundred wheels exerting a pressure of five tons each will create seven thousand five hundred tons pressure. This weight distributed on twelve rails would require one hundred and twenty-five wheels on each rail. The outer rails would be about forty feet apart, hence the ground covered by the wheels would be equal to a space three hundred and seventy-five by forty feet, or fifteen hundred square feet. The pressure, therefore, would be only one-half of a ton to each square foot of earth.

The question has been asked, "How can you equalize this pressure upon the various wheels?" The car which carries the ship will be made of plate-iron cross-girders of sufficient depth and strength, and of such number as are needed to carry the entire load, even if each girder had no support between the two outside rails of the track; therefore the weight from the keel to each side can be distributed over all the rails of the system. In distributing the pressure lengthwise, it should be borne in mind that the ship possesses enormous strength to resist bending, and, besides this, that she cannot bend in the direction of her length on the car, unless the earth gives way under her, hence no longitudinal strength in the car itself is really necessary. The mid-ship section, being much the heaviest, would produce a greater pressure per foot than an equal length of the ends, but this section is balanced by leaving a certain portion of the ends unsupported. The car which would carry a ship four hundred and fifty feet long would not be over three hundred and fifty feet, hence fifty or sixty feet of each end of the ship would project over the ends of the car. In this way, the wheels at the ends of the car would be made to bear as much as those in the middle. In floating-dock, vessels usually have a very considerable portion of their ends without support. Their sides, at the bow and stern, rise directly from the keel, and give great strength to these parts. An intelligent and reliable correspondent wrote to me recently that he had witnessed the long and tedious launching of the Great Eastern. She was parallel to the river, and the ways only occupied one hundred and fifty feet of the middle of the ship, leaving two hundred and sixty-four feet of each end without support.

It is not important that each wheel should bear exactly as much as its neighbor. Although five tons would be the maximum average load, each one would be tested to bear at least four times as much, and, in practice, it might occasionally be required by inequalities in the road, or even in the distribution of the load, to bear twice as much. The car-wheels on railways are frequently compelled to bear three or four times as much while the trains are moving at high speed as they do when at rest.

Let us now compare this pressure of half a ton per square foot, imposed by a large vessel on the road-bed, with that which we see

applied every day to the earth. A man compelled to use crutches carries his whole weight on the ends of them. On a hard dirt road they leave scarcely any sign of the pressure. Assuming his weight to be one hundred and eighty pounds, and the end of each crutch to be equal to two square inches, his weight will be carried upon one thirty-sixth part of a square foot, which is equivalent to six thousand four hundred and eighty pounds pressure to the square foot, or about six and a half times the pressure that would be brought to bear by the weight of one of the largest class of steamers. A horse, when trotting, carries the weight of himself and rider on but two of his feet at each step; yet, on a dry dirt road, his shoes hardly leave their imprint. The area of each shoe will not exceed twelve square inches. If the horse and rider weigh twelve hundred pounds, the pressure would be more than seven times as great as that which the earth would sustain under the ship-railway, with its heaviest load. A brick wall, only one story high, presses the earth more heavily per square foot than the heaviest ship could on the ship-railway. When ships are launched, the two narrow launching-ways which carry them, press the earth with from three to five times as much force per square foot without settling.

It is a mistake to suppose that ships are not sometimes taken out upon dry-docks with full loads in them. One of the largest German steamers, fully loaded, was taken out within the last twelve months and put upon a dry-dock in New York without the slightest injury, and vessels with their cargoes are frequently taken out on the docks in England and elsewhere.

The bill before Congress in aid of the ship railway requires that a guarantee of six per centum dividends on fifty million dollars, or two-thirds of the capital stock of the company, shall be made by the United States for fifteen years, the guarantee not to include the principal. It is only to take effect after the entire practicability of the plan is proven. Ten miles of road, and the necessary terminal works to take a loaded ship out, are to be first built, and then tested by transporting the ship and her load over the ten miles of railway at a speed of at least six miles per hour, and replacing her in the water again without injury to the ship, the railway, or the terminal works. Even when this is done, the guarantee is only to attach for five million dollars. As each additional section is completed and tested in this way, the guarantee for a proportional amount is to attach. As each ten millions of stock is guaranteed, the severity of the test is increased. For the first ten millions, the weight of ship and cargo is to be 2,000 tons. The next test will be 2,500, then 3,000, then 3,500, and finally 4,000 tons. In consideration of this guarantee, the company agrees: *First*—To transport, for ninety-nine years, the ships, troops, property, and mails of the United States free. *Second*—To carry no other war vessels, or contraband of war of any nation at

war with the United States. *Third*—That all net receipts in excess of a sum sufficient to pay six per cent. dividends shall be paid to the United States, to refund any advances they may have made on account of the guarantee. *Fourth*—To give the United States the right to reduce or increase the tolls at her pleasure, provided the reduction shall not prevent the earning of eight per centum dividends. *Fifth*—To give her the right to discriminate in favor of American and Mexican commerce when fixing the tolls.

To avoid any question as to what are net receipts, the company agrees that one-half of the gross receipts shall be deemed sufficient to pay operating and extraordinary expenses, repairs, etc., so that when the total receipts are six million dollars per annum, the United States will incur no liability under its guarantee.

The grant from Mexico gives to the company the right to offer these advantages to any other foreign Government that will aid the enterprise with money or guarantees.

The popular feeling in the United States has unquestionably, until quite recently, been favorable to Nicaragua, and many arguments have been advanced in its behalf. Every one of these is doubly powerful when applied to the Isthmus of Tehuantepec. The whole question between these two locations must depend on the answer to this inquiry, namely: "Is the ship railway practicable?" No engineer, so far as I know, has yet publicly expressed any doubt of it. On the contrary, some of the ablest engineers and ship-builders in the world have expressed implicit confidence in its practicability.

If we consider the healthfulness of the two isthmuses, there can be no question as to the superiority of Tehuantepec. If we look at the shortness of the routes, Tehuantepec still has the advantage. When we compare the canal and its numerous locks and the delays incident to their use, to say nothing of the danger of their derangement, with the certainty and celerity of transit by railway, the superiority of Tehuantepec is no less marked. It is claimed that the Nicaragua Canal will complete our coast line between the Atlantic and Pacific; but how much more secure and complete will it become, if we exclude from it a foreign coast line on the Isthmus as long as that which extends from the capes of Florida to Newfoundland! This will be done by the ship railway at Tehuantepec.

Much has been said and written of the importance of cultivating more intimate commercial relations with Mexico, and no thoughtful merchant or statesman can fail to concede it. In the first place, she has a government fashioned after the plan of our own, and we should on this account, if on no other, be bound to her by the strongest sympathy. Her soil is wondrously fertile and productive. Hidden in her mountains, within the easy reach of enterprise, lie stores of gold and silver in fabulous amount. Many articles of commerce which we require, but can not produce, are brought to great perfec-

tion there, and her people require innumerable manufactured articles, commodities, and productions which we could supply to them, with great profit to us and advantage to them. There is, indeed, no good reason why we should not enjoy almost all of her commerce.

There can be no doubt that the construction of the ship railway at Tehuantepec will greatly stimulate intercourse between us, and it must bind the two nations more firmly together, socially, politically, and commercially.

I will not, at this time, dwell upon this important topic, but will simply refer to the following table, taken from official records, showing the commerce with the various nations therein specified:

British India	$423,000,000
Australia	375,819,000
China	198,000,000
Hong-Kong	112,000,000
Peru	75,000,000
New Zealand	71,782,000
Chili	58,000,000
Japan	55,230,000
Philippine Islands	34,768,000
Tasmania	14,885,000
Hawaiian Islands	7,524,000
	$1,425,953,000

Of this vast commerce the United States enjoys but four per cent., and even in this trifling percentage the Mississippi Valley is debarred by the Isthmus from all participation.

Our sister republic of Mexico has been most liberal in concessions in aid of the ship railway. Realizing the great benefits that will inevitably follow its completion, she has given everything in her power to make it a success. *First*—She exempts all property of the company and its capital stock from taxation during the entire period of ninety-nine years. *Second*—She permits the importation, during the like period, of everything necessary for the construction and operation of the railway. *Third*—She gives a right of way across the Isthmus a half mile in width. *Fourth*—She donates to the company a million acres of the public domain. *Fifth*—She exempts all the money required to pay debts and dividends of the company abroad from the present export duty of six per centum; and *Sixth*—She agrees to protect the works with her army and navy, at her own expense. But this is not all. Anxious to cultivate more intimate relations with us, Mexico offers to the United States Government rights and privileges greater than any ever before extended by her to either government or individual. She says to the United States: You may regulate, at your will, the tolls of this company. You may reserve the right to discriminate in favor of your own commerce. You may accept an assignment of the revenues of the road, and our courts

will protect you in its enjoyment. Come, join us in consummating the most important work of modern times—a work which, when completed, will bring manifold blessings to you and to us. What answer will the United States give to this earnest invitation? It comes from a nation which, but recently emerging from the throes of foreign invasion and domestic revolution, has, through the wisdom of her rulers, established herself upon a firm basis, and promises in time to rank high among the nations. Just now her treasury is depleted, and the masses of her people are poor, although there is probably no equal area of territory on the earth so rich in undeveloped wealth. But her present poverty has not prevented the exercise of a statesmanlike liberality in dealing with this great question. Her invitation is made to the foremost nation on the earth—one whose credit is second to none, and whose wealth and resources are illimitable. She offers an opportunity to solve the great problem of centuries, and to assert the Monroe, or rather the American, doctrine, not by idle declaration, nor by force of arms, but in a way to command the respect of the world. The United States to-day enjoys but five per cent. of her entire foreign trade: ninety-five per cent. of that valuable and growing commerce is controlled by foreign nations. Will the United States reverse these figures? or will she disregard the overtures of Mexico, decline her liberality and reject her commerce by refusing to join with her in opening, for mutual benefit, the grandest commercial highway ever projected?

JAS. B. EADS.

REVIEW

OF CAPT. PHELPS' PAMPHLET, ENTITLED "TRANSPORTATION OF SHIPS ON RAILWAYS." TWENTY-SEVEN MISTAKES CORRECTED

Capt. S. L. Phelps' pamphlet, entitled "Transportation of Ships on Railways," is so full of errors that a brief exposure of them is necessary to prevent wrong impressions.

It contains insincere statements of facts about which he is no doubt fully informed; and absurd errors in naval architecture and civil engineering, which betray a lamentable want of knowledge of some of the simplest physical laws. To give an idea of the number

of these errors, I will enumerate them as I proceed, and leave the reader to refer each to its proper origin.

1st. Captain Phelps refers to General Barnard's survey of the Isthmus of Tehuantepec, made *twenty years* ago, to show that the grades and curves for a ship railway must be excessive, but he is quite silent about other surveys for railways made since, which have developed better lines. He says: "If a ship can be hauled up gradients of 115 to 150 feet per mile, then the elevations can be surmounted, provided the ship can first be changed sufficiently in inclination to the horizontal."

Mr. E. A. Fuertes, an eminent civil engineer, now Dean of the Department of Civil Engineering in Cornell University, was chief engineer of Commodore Shufeldt's expedition, which surveyed the Isthmus only nine years ago. In a recent letter to me he says: "I can assure you, upon knowledge of every inch of the ground, that you will find no difficulty about curves, grades or bridges. The ascent of the Atlantic slope will offer no more difficulties than the Hudson River Railroad, and on the Pacific side, either one of the three passes in the neighborhood of Tarifa or Chivela will allow of no steeper grades than 25 to 35 feet per mile to bring you down to the Pacific plains."

2d. Captain Phelps says: "The displacement of a number of steamships in service indicate weights of ship and cargo reaching from 9,000 to 12,000 tons, their length being from 450 to 500 feet and upwards. Hence, ability to carry a ship and cargo weighing 12,000 tons is necessary."

Captain Phelps cannot cite a single merchant steamer in service (the Great Eastern excepted) whose displacement is 9,000 tons when loaded, much less 12,000. Lloyds' register will show that 90 per cent. of the world's commerce is carried in vessels, the largest of which will not, when loaded, weigh over 4,000 tons. But three steamers in the world (except the Great Eastern) are in service that exceed 450 feet. These are the Britannic and Germanic, which only exceed it by five feet, and the City of Berlin, which is 488 feet long. One or two are building that are over 500 feet, but they are not in service.

3rd. Captain Phelps declares that tilting tables to change the grades on the road will weigh 24,000 tons each, and says: "This change in inclination would become necessary many times in the distance across the Isthmus."

The tilting tables, if necessary, would not weigh more than one-tenth of 24,000 tons. But the surveys already made, and those referred to by Mr. Fuertes, prove that the grades are so easy that such devices as tilting tables will be wholy unnecessary.

4th. Captain Phelps says, under the head of "Change of Direction:" "This would be frequently necessary in that mountain country, and can only be effected by the use of turn-tables, which

must be 500 feet or more in diameter, and must carry 24,000 tons and their own weight, which would probably approximate to the weight carried, or say another 24,000 tons, and the whole weight would again be 48,000 tons, more or less."

Surveys thus far made show that but three turn-tables to change the direction of the road, will be necessary. Careful estimates prove that the car to carry the ship will not weigh more than one-quarter as much as the heaviest vessels to be transported, or say 1,500 tons. This, with 6,000 tons for the ship and 500 for the engines, would be but 8,000 tons on the turn-table, instead of 24,000. Pivot draw-bridges are now in use on the Mississippi River which are 460 feet long. A turn-table for the ship railway will be no longer, and with its wheels, etc., would not weigh one-tenth as much as Captain Phelps asserts. Hence, with a 6,000 ton ship the entire load, turn-table and all, would not be one-quarter of 48,000 tons.

5th. He estimates the ship and the car, cradles and supports to carry the ship, at 24,000 tons.

This estimate is three times as great as it should be.

6th. He says: "The model of the ship must be known that cradles and supports can be made in advance to accurately fit her form."

Without investigating the strength of ships, he has adopted the popular error that their sides are so weak that supports must be put all around them when out of water. If a barrel of beans be afloat, the water will support its sides just as it does a ship, but it does not follow that it must be carefully laid on supports, hollowed out to fit it when taken out of the water. The supports on which the ship rests in a dock are placed chiefly under her keel, and the remainder under the flatter parts of her bottom. By very simple devices these are made adjustible to suit a variety of vessels of similar tonnage. A number of different-sized cars would be provided to suit the different classes of vessels. The same car that would be suitable for large steamers would not be used for sailing vessels.

7th. He says: "No two vessels have the same form, and cradles must be fitted for each vessel carried."

This statement is likewise erroneous. The Germanic and Britannic are alike in form; so are the Baltic and Oceanic; so are the Celtic and Adriatic. I could name scores of vessels whose forms are alike, if I had space.

8th. The Captain says: "Builders, owners, seamen and underwriters all condemn the railway plan as impracticable, if for no other reason than that ships cannot be taken out of water safely with cargo on board."

Here are three distinct misstatements: 1st. Builders do not all do any such thing. Messrs. Edward Hartt and F. L. Fernald, of the United States Navy, and E. J. Reed, of the British Navy, are builders

whose scientific education and practical experience in constructing wooden and iron ships of the largest sizes entitle their opinions to the highest possible degree of respect; and they have declared over their own signatures that the proposed ship railway is not only entirely practicable, but for several reasons is superior to a canal. 2d. Seamen do not all condemn it. Commodore Shufeldt, Captain Silas Bent and Commander Farquhar, seamen whose education in the United States Navy and whose standing and experience entitle them to quite as much respect as Captain Phelps enjoys, do not condemn it, but encourage me to go on with the work. 3rd. It is untrue that ships cannot be taken out of water safely with cargo on board. A letter dated February 14th, from Mr. William F. Buckley, President of the New York Balanced Dock Company, gives the following list of vessels taken out on his dock with cargoes in them:

Ship Great Victoria, 2,386 tons.
" Triumphant, 2,046 tons.
" America, 2,054 tons.
" Hagerstown, 1,903 tons.
" S. C. Blanchard, 1,903 tons.

Steamer Colorado, 2,765 tons.
" Rio Grande, 2,565 tons.
" Thingvalla, 2,436 tons.
" Monarch, 2,366 tons.
" Lepanto, 2,310 tons.
" State of Nevada, 2,488 tons.

Mr. Buckley in his letter says: "We do not refuse any class of ships or steamers, even with their coals and cargoes on board, whose length does not exceed the length of the dock. In every case in which we have taken up steamers with cargo in, it has been done without the least strain or injury to the vessel. As the rule is to make a charge for raising cargo in the vessel, they usually come to us without cargo."

11th. Starting on the hypothesis that vessels will weigh two or three times as much as they really do, and that the cars must be three times as heavy as need be, the Captain says: "Allowing five tons pressure upon each wheel under the ship car, there would be required 4,800 wheels. These placed at three feet center to center, would require 14,400 feet of rails, or twenty-eight rails of 500 feet in length, or two and one-third times more than Captain Eads adopts; and the rails, if under the ship, would hardly be twenty inches apart!"

If Captain Phelps had indulged in a greater flight of fancy, and started with ships of fifty thousand tons weight, he could have drawn conclusions still more startling and equally unreliable.

12th. The Captain makes the following remarkable statement: "When in motion, the ship would practically rest upon four points.

When cars have four wheels, the weight is equally distributed over them; add two wheels, and four of the six will still carry the load, but the weight will be transferred momentarily according to deviation in the plane passed over. This source of disaster from overloaded wheels would be a constant danger."

This is the sheerest nonsense imaginable. Mr. J. J. Mann, superintendent of the Chicago, St. Louis and New Orleans Railway, informs me that the two-story brick depot in Jackson, Tennessee, was moved 700 feet north, and 20 feet east of its original location. It is 140 feet long and 40 feet wide. It weighed vastly more than the Egyptian obelisk recently erected in New York, and was moved without cracking its walls. It had probably 500 rollers under it. Captain Phelps would lead the reader to believe that it must have rested at times upon only four of them. The same building could be moved 7,000 feet or 700,000 feet in the same manner and with equal safety.

13th. The Captain says: "In a distance of 150 to 180 miles there must be several sidings for passing ships and many 'turn-tables,' besides frequent tilting-tables for changing the inclination of the ships to the horizontal."

Evidently Captain Phelps had forgotten that in another part of his pamphlet he says: "The ship railway involves about as much canal as the Nicaragua route." And in another, that "the Isthmus is 143.5 miles wide." The Captain should have a better memory. 180 miles of railway and 173 miles of canal is rather too long to get across an isthmus only 143.5 miles wide. 33 miles will be river navigation and 12 miles of bay, leaving about 100 miles of railway.

14th. He says: "The weight to be transported is equivalent in amount to over 1,200 freight cars and their load."

I have shown that the maximum weight to be transported is only 8,000 tons. Hence it is only equal to 400 freight cars and their loads.

15th. The Captain gives his readers the following sample of his knowledge of railway engineering: "The ship in view is one-tenth of a mile in length. A change in the inclination of the road-bed from the horizontal to grades of ten, twenty, fifty or more feet in a mile would suspend this vessel by the ends while entering upon the new gradient. At one point the ship's middle portion would be, in such changes, from six inches to two and one-half feet, and so on, above the level of the platform car, and would not therefore rest in the cradle at all."

Now, let us suppose the grade is ten feet in a mile. In the length of the ship which is the tenth of a mile it would be one foot. Let us suppose the worst possible case—that where the change of grade is made abruptly from a level plane. When the ship has advanced half her length up the grade, one end will be just six inches higher than the other, and the angle where the grade changes will only be three inches further from the ship than if the change did not occur—

just half as much as Capt. Phelps states it. This is the position where the middle of the ship, if absolutely rigid, would be at the greatest distance from the track. Hence, if the ship be 528 feet, or one-tenth of a mile, long, and a grade of 50 feet be made to form an angle with a level plane, the middle of the ship can only be one and one-fourth feet further from the angle, and not two and one-half feet, as stated. It is easy to see that if the grade line and the level were united by a vertical curve only as long as the ship, with a versed sine or deflection of seven and one-half inches, the middle of the ship would then only be half as far from the track. But there is no reason why this curve should be limited to the length of the ship. The change of grade may be made in one or two, or even three miles, instead of at one point, and the possible bending of the ship will be thus almost wholly prevented. The great box tubes of the Britannia Bridge are nearly 500 feet long and are as strong as any ship, yet they bent several inches with their own weight when erected, and are deflected from one to three inches more with every passing train. A ship 528 feet long would bend six inches in her length without injury, but on the ship railway the change of the grade will be so gradual that no perceptible bending can occur.

16th. The Captain says: "A ship while out of water is the heaviest of structures for its strength."

This is wholly erroneous. Very few ships are as heavy as the brick depot that was moved so far in Jackson, Tennessee. Yet any ship of half its weight is vastly stronger. Hence it is a much lighter structure for its strength.

17th. The Captain thus displays his knowledge of physics. He says: "Resting in the water, the ship is sustained by a medium entirely surrounding the bottom and pressing in *equal force* upon every inch of its surface."

This is a mistake. The water presses against the deeper parts with greater force than it does against the parts not so deep. The pressure at any point depends upon the vertical height of the water above that point.

18th. Again, we are told: "Whether rolling or pitching, the support from the water is uniform, at all times and at all points."

This is a most astonishing statement, when we remember that it comes from one who was once a captain in the United States Navy. In storms the pressure upon any one part of the hull is constantly changing. If the support were "uniform at all times and at all points," such a thing as a ship being strained in a storm or foundering at sea would be unheard of.

19th. Captain Phelps tells us: "Moreover, there is comparatively little motion in the bottom of the vessel, whatever there may be thirty, forty, or fifty feet above it, because motions at sea are from the bottom as the center."

This will be news to naval architects who have hitherto carefully considered the various weights, and their positions in the ship, to determine the center of gravity and the metacenter of the vessel, so as to secure the greatest degree of steadiness for her. Capt. Phelps has made the novel discovery that *the bottom* of the ship, and not her center of gravity, is the center of motion.

Capt. Coles, R. N., the builder of the celebrated and unfortunate British turreted ship "Captain," made the same mistake on this point that Capt. Phelps has made, and it cost him his life. The center of gravity of motion in the "Captain" was so high (that is, so near the metacenter) that when the ship got to rolling, a slight squall was sufficient to overturn her. She carried Capt. Coles and almost every soul on board to the bottom. This could not have occurred if "motions at sea are from the bottom as the center." The center of motion in this case was probably thirty feet above the bottom.

I was in England when the 'Captain' was being built, and desiring some information about her, I sought Mr. E. J. Reed, the chief constructor of the navy, and learned from him, with surprise, that he had nothing to do with her, as she was placed by the government wholly under the charge of Captain Coles, because he, Reed, had disapproved of Coles' designs. The sequel proved that a man educated to navigate a ship is not always familiar with the scientific principles involved in her construction and servitude; and still less frequently is he competent to apply them in practice. Shipbuilding has, in the present century, advanced from the category of mechanic arts. It is now recognized as one of the sciences. Some of the ablest mathematicians and engineers of the present age have devoted years of labor in elucidating the principles involved in its problems.

It is true that many ships, probably the majority of them, are built by men wholly unfamiliar with the mathematical processes by which the various members of the vessel are proportioned; but these have been tabulated in what are known as Lloyd's Rules. These rules require that vessels of certain tonnage shall have plates, beams, ribs, kelsons, etc., of certain dimensions in certain parts of the ship, while these dimensions are again modified according to the proportionate length, breadth, and depth of the vessel. Unless vessels when completed are built in accordance with these rules, the Underwriters decline to insure them, or charge increased rates for so doing. Hence, a mechanic familiar with plate-iron work, or boiler-making, may establish a ship-yard, and if possessed of sufficient knowledge of the *art* of ship-building to transfer the lines of a small model to the floor of his molding loft, may, by the observance of Lloyd's Rules, become a successful builder, without knowing much more about the science of ship-building than Capt. Phelps does.

Such builders may, upon the solicitation of Capt. Phelps, declare the ship railway totally impracticable. But certainly the opinion of such persons should not be put in the scale against men like E. J. Reed, Edward Hartt and F. L. Fernald, constructors who have studied the science of ship-building as a profession, who are competent to revise Lloyd's Rules, to determine the intensity of any strain to which a vessel may be subjected in the water or out of it, to ascertain its ability to resist such strain, and who have an extensive practical experience in the mechanical details of their profession.

20th. Capt. Phelps says: "The Suez Canal, 100 miles long, costs $800,000 yearly. The Nicaragua Canal proper is 53.17 miles long."

The reader would infer from this deceptive statement that the Suez Canal is nearly twice as long as the Nicaragua. Much of the Nicaragua route lies through the Lake, and much of the Suez route is through the Bitter Lakes. These had to be dredged to deepen them, and much dredging must be done through Lake Nicaragua to deepen it. When storms prevail this part will be very difficult to navigate, as vessels will be liable to be blown out of the cut and stuck in the mud. They frequently ground in the lakes at Suez. It requires two days to pass through the Suez Canal, although it is only ninety-six miles long. As the Nicaragua route is nearly twice as long, it would probably take three or four days to go through it, if, like the Suez Canal, it had no locks; but as it must have many locks, these will add another day or two of delay. The French engineers, knowing the great danger of accidents to the locks, as well as their delay, wisely determined to have none of them at Panama.

21st. The statement that the Suez Canal costs but $800,000 yearly is another error. I have before me the report of the three British directors (given to me by one of them), in which it is stated that it cost, in 1878, 6,248,663 francs, which is equal to $1,249,732, or nearly 57 per cent. more than Capt. Phelps would make the reader believe.

22d. Capt. Phelps says: "As projected, the railway scheme involves about as much canal as the Nicargua route, and will have *two locks*."

Here are two misstatements, and it can scarcely be possible that Captain Phelps was ignorant of the facts in either case. 1st. It is not contemplated to have a canal through more than five or ten miles of swamp to connect the Uspanapa River with the firm lands beyond. 2d. There will be no locks at all in the entire route. The two ends of the railway extend, with a grade of but one foot in one hundred, down under water far enough to float the vessel over the car that is to carry it. Hence locks will be unnecessary.

24th. Captain Phelps says: "The distance saved for steamers by way of Tehuantepec between the Atlantic and Pacific ports of our country would be only 510 miles, as compared with the distance via the Nicaragua route."

This statement is probably made on a system of general average. Having extravagantly overstated so many other matters, the Captain evidently wishes to average his errors by extravagantly understating this distance. Hon. C. P. Patterson, Superintendent of the Coast Survey, informs me that the difference in favor of the Tehuantepec route from the mouth of the Mississippi to San Francisco, over the Nicaragua route, is 1,193 nautical miles, or 1,372 statute miles. And that between New York and San Francisco it is 753 nautical or 860 statute miles.

25th. He says: "The estimated cost of the canal is $41,000,000; that of the railway, for which no surveys have been made, is $75,000,000. Doubling these estimates to cover all kind of contingencies, will make the canal cost $82,000,000, and the railway $150,000,000."

As he is no doubt familiar with his own estimates, we must concede to him the right to double them as often as he thinks necessary. But being satisfied with the estimates we have made for the ship railway, and which Captain Phelps has never seen, we object to his increasing them simply because he finds his canal estimates so largely understated.

26th. The Captain says: "Ten million gross receipts for the railway would, after deducting 60 per cent. for expenses, leave $4,000,000 net, or 2⅔ per cent. on outlay. The average expenses of railways bear a larger ratio to receipts than 60 per cent., and it cannot be doubted that, if in any degree practicable, the ship railway would be enormously expensive in proportion to gross receipts."

Here the Captain is again mistaken; several first-class roads are worked for less than 50 per cent., and they handle their cargoes by hand. In the ship-railway it would be handled exclusively by machinery, thus greatly reducing the expense, and as every thing must be of the most substantial character, the ratio of expense of maintenance will be much less than with ordinary roads.

27th. Captain Phelps says further: "The United States are asked to fasten this needless tax on the country, and to do it by putting up a vast sum of money to try an experiment for which a favorable result cannot be anticipated."

I can only account for this inexcusable misstatement by the fact that Captain Phelps had become so careless in making the twenty-six others which I have already exposed, that he determined to "cap the climax" in this one.

The United States is not asked to put up a vast sum of money to try an experiment. It is not asked to put up a dollar for any such purpose, and if the Nicaragua scheme can only win support by such totally unfounded statements as these, its intrinsic merit must be small indeed. The "experiment," as Captain Phelps calls it, is to be made by private capital alone. Ten miles of railway with its requisite cars, engines, etc., and the terminal works for taking a ship,

weighing with her cargo 2,000 tons, out of the water on to the road, are to be built with private capital. When this is done, if the experiment of transporting this loaded ship, without injury, at six miles per hour over the road is a failure, the United States loses absolutely nothing. Only after this has been successfully done is the Government liable, and then for only 6 per cent. dividends on $5,000,000 stock. The total amount of stock to be guaranteed is but two-thirds of the amount of the $75,000,000 required to build the road. Like amounts of stock are only to be guaranteed as other sections are finished and tested. The tests increase in severity from time to time; the last $10,000,000 guaranteed depends upon the safe transportation of a ship, weighing, with her cargo, 4,000 tons, over the entire line at six miles per hour. A ship of this size would be taken for the first test, but the harbors must be deepened before so large a ship could enter them. This is as large as any ship which has yet visited New Orleans, although there has been 30 feet depth through the jetties for the last eighteen months. Captain Phelps declares at one moment that this cannot be done, and in the next he betrays his fear that it can be, by striving to prevent me from doing it at my own cost and risk. To defeat a trial of the experiment, he does not hesitate, as we have seen, to make a statement which totally misrepresents the facts, and actually tells the reader that *the United States is asked* "to put up a vast sum of money to try an experiment for which a favorable result cannot be anticipated."

I have not space to follow Captain Phelps through the misrepresentations, absurdities and nonsense with which his pamphlet abounds, but which are nevertheless so stated as to mislead many intelligent persons who do not take the time to examine the subject. The twenty-seven which I have pointed out show that he knows nothing about the principles of the problem he undertakes to argue, and that he is very reckless and unfair in his statements.

As it is not to be supposed that his pamphlet could have been published without being first examined and approved by the chief promoter of the Nicaraguan scheme, Admiral Ammen, he must, unless it be disavowed, become equally responsible for its ridiculous blunders and deceptive statements.

To avoid discussing the real merits of my proposition, other unfair opponents strive to create the impression that I am asking *a government guarantee to pay for making an experiment.* The guarantee is not asked to pay for an experiment, successful or unsuccessful. It is asked in consideration of certain valuable benefits which my grant from Mexico enables me to give to the United States, or to any other government which will aid the construction of the ship-railway.

In consideration of the guarantee, I agree 1st, to transport the war vessels, troops, property and mails of the United States free for 99 years. 2nd. To give to it the right to reduce the tolls on the road.

3rd. The right to discriminate in favor of its own commerce and that of Mexico when fixing the tolls. 4th. To transport no vessel of war belonging to any nation at war with the United States; and 5th, To pay back to the United States every dollar that may be advanced under her guarantee.

As the ship-railway is opposed on the ground that it is an untried experiment, the actual demonstration of its practicability is to be made at the risk of myself and associates, before any liability on the part of the United States can possibly take effect. And as it is charged that my grant from the Government of Mexico does not authorize me to give to the United States the above valuable advantages, the guarantee is also not to take effect until after the Mexican Congress shall have signified its assent to the proposed agreement.

Captain Phelps shows his unfairness in the premises by republishing in his pamphlet the misstatements of the New York *Times* of Feb. 3d, conveying certain false impressions which were fully exposed and corrected by me a few days afterward. The *Times* lays much stress upon the fact that the grant contains a clause which declares that "The company shall be Mexican even though some or all of its shareholders be foreigners, and shall be subject exclusively to the jurisdiction of the tribunals of the Republic in all matters of which the cause of action may take place within its territory." It will be seen that the proposition made by me to the United States does not propose to give to it any right of eminent domain on Mexican soil, nor any right to interfere in the control of the road. It will, if accepted, be simply an agreement between the ship-railway company and the United States, sanctioned by Mexico. Mexico could not give to the United States the right to discriminate in favor of our commerce on the railway without conceding to other nations with whom it has treaties, the same advantages. The usual treaty clause which provides that the nation making the treaty shall enjoy all the rights and privileges of the most favored nations, would give to each nation having such treaty with Mexico the same right in favor of her commerce. By the concession, however, she gives the company the right to charge certain maximum rates of toll, and leaves it optional with it to charge as much less as it pleases. It does not impose upon the company any obligation to make the tolls uniform to all nations. The grant requires that the road shall be open to the *commerce* of all nations at peace with Mexico, and they will have a right to use it at the maximum rates of tolls, or at such lower rates as it may suit the interests of the company to fix. It does not require the company to transport the war vessels of any nation but Mexico. Nor does it forbid the transit of such vessels belonging to other nations except in case of war.

The grant was drawn for a different purpose from that which was contemplated by either the Panama or the Nicaragua concessions.

They are for the benefit of Europe first and of America afterwards. This is the American route, and the ship railway is for the benefit of the commerce of North America first, and that of the world afterwards. It is the American route, because it is 1,500 miles nearer by it from our ports on the Atlantic to those on the Pacific, and 2,200 miles nearer from the mouth of the Mississippi to our Pacific ports than it is by Panama; and although these distances are somewhat less by Nicaragua, the greater delay in passing through the latter route would destroy all benefit which the saving in distance would otherwise make. Mexico gives most valuable aid to the enterprise, and she has a right to expect benefits greater than those which are to be enjoyed by nations who give no aid to it. If the United States aids it, she will enjoy all the advantages reserved to Mexico, and discriminations will be made by the company in favor of the commerce of the two countries in consideration of the aid which they give to the company. Mexico gives authority to the company to secure aid from some other government, and it prescribes the manner of doing it. Like any other nation that has achieved its independence, it is jealous of any foreign domination of its territory, and hence it declares that any sale, mortgage or transfer of the railway, franchise or lands of the company to any other government, shall work a forfeiture of the grant; but it declares that the company may hypothecate the revenues of the road to any other government that will aid it with money or guarantees, provided the terms of such hypothecation do not conflict with the other provisions of the grant, that is to say: provided the company does not give to such government the right to take possession of the road and the right to operate it, or to acquire title to its lands. It gives to such government only the right to intervene through the courts of Mexico, in case of any bad faith of the company, and to have receivers appointed by its courts to collect the revenues and disburse them according to the terms of the agreement with the company. Any one who supposes that any independent government would consent that another government should enter upon its territory and take charge of a railway within its borders, or come into possession of any important works upon its soil, knows but little of international affairs. The United States would scarcely be able to make such an arrangement with any one of the weak States of Central America that requires its protection. It has no right to ask of Mexico that which it would not itself grant to any other independent government. Mexico will protect the United States in the full enjoyment of all the benefits the ship railway company offers to give her, and that is all she needs. When she refuses to recognize and consent to the terms I offer to the United States, it will be time enough for Captain Phelps and Admiral Ammen to repeat the *Times*' misstatements.

Captain Phelps closes his pamphlet with several letters expressing

adverse opinions as to the practicability of the ship railway. In one of these Mr. John Roach says: "In my opinion a ship or steamer of large dimensions cannot in safety be taken out of the water with cargo on board, as there would be great danger of injury to the hull, and consequently cannot be safely transported with cargo on a ship railway."

As Mr. Buckley gives the names of five large ships and six large steamers that were taken out on his dock with their cargoes on board, and without injury, it is evident that Mr. Roach's opinion is based upon incorrect premises, and is therefore without value. Several large vessels have been taken out with their cargoes on board, in the docks and on the ways of Messrs. Cramp & Sons, of Philadelphia, and others have been taken out on other docks, besides Mr. Buckley's, in New York, but I have not yet had time to ascertain the names and sizes of these vessels.

In a printed letter addressed to Hon. J. Floyd King, over the signature of Admiral Ammen, the above letter of Mr. Roach is preceded by the following:

"The New York *Herald* of March 10th, 1880, states that Captain Eads said before this committee that E. J. Reed, formerly Chief Naval Constructor of Great Britain, Mr. John Roach, an eminent ship builder, and Mr. Henry Steers, had received his plans with favor."

I have never stated to anybody that Mr. Roach received my plans with favor. I stated to the committee referred to, that in answer to my question as to how much Mr. Roach thought the bow and stern of a ship 450 feet long could be jacked up without danger to the ship and without lifting her off the central blocks, that he had replied: "Six inches." This is the extent of my statement respecting the opinion of Mr. Roach.

After the letter of Mr. Roach, however, is this statement: "Wm. H. Webb, Esq., the celebrated ship-builder, concurs in this opinion."

Mr. Wm. H. Webb informs me that this statement was published without authority, and that he never expressed such concurrence of opinion.

Admiral Ammen, in the letter referred to, makes the following statement also:

"The first proposition I saw published by Captain Eads referred to the transportation of water-borne vessels. The letter of Mr. Reed, published in the Washington *Post* to-day, would seem to refer to similar conditions."

The impression herein conveyed is, that I was then proposing to transport ships in caissons, or tanks of water. I never proposed any such thing, nor does Mr. Reed's letter convey the impression that he proposed such method.

A letter from Messrs. Harlan & Hollingsworth is given by Captain Phelps, in which they say: "If the foundation of the railroad, having

six tracks, could be made *substantial, so as not to yield* under the immense weight of a loaded ship, we believe that a cradle could be constructed to receive the ship and transport it the distance named without injury."

This is certainly not damaging testimony to the ship railway. The Atlantic works of Boston are also quoted. They start with this declaration: "Our positive ignorance of this matter throughout forbids our expressing any opinion at length." They say: "Were it not that Captain Eads has already done wonderful things, we should not hesitate to declare this scheme impossible of execution." This certainly modifies very much any adverse opinion advanced in the same letter.

Under the head of "Opinions of Civil Engineers," there is the statement that "the Hon. John Conness, formerly of the United States Senate, has forwarded the following expression of opinion of an able engineer: 'Admiral Ammen's testimony before the select committee tells the whole story, and puts Eads' absurd project in its right light.'" As the name of this able engineer is not given to the public, it is not necessary to quote his opinion further.

The only civil engineer whose name is published by Messrs. Ammen and Phelps as doubting the practicability of a ship railway across the Isthmus of Tehuantepec is Mr. W. J. McAlpine, who, it is said, has written "That he regarded the Eads scheme quite as visionary as M. de Lesseps' canal at the ocean level, and that he would discuss the subject without delay." He is pronounced by Admiral Ammen "one of our most eminent engineers," and by Captain Phelps is further indorsed "as second to no engineer in this country." Mr. McAlpine's opinion would have commanded greater weight if he had not been president of a convention of engineers in St. Louis in 1867, which unanimously declared that the long spans and deep foundations of the bridge I was then building were totally impracticable.

ADDRESS

Before the British Association, at York, England.

Amongst the invited guests at the meeting of the British Association at York, September 5th, 1881, was Mr. James B. Eads, C. E., the constructor of the St. Louis Bridge, and of the jetties at the mouth of the Mississippi. At the meeting of Section G, over which Sir W. Armstrong presided, he was urged to deliver an address upon the improvement of the Mississippi, and also to speak upon the proposed ship railway across the Isthmus of Tehuantepec. Mr. Eads replied that he was merely present for the day as a guest, and not expecting to have the honor of an invitation to address the meeting, he was totally unprepared to do so. However, being pressed, he consented to occupy half an hour of the time of the section in explaining the improvements of the Mississippi, and another upon the subject of the ship railway. Notice was accordingly given on Thursday that after the President's address Mr. Eads would speak upon the above-mentioned subjects. The section met in the hall of the Corn Exchange, and at the appointed time, 1 o'clock, a large and attentive audience was present. Mr. Eads, as already stated, delivered his address extempore, and not from a written paper. We give the substance of his remarks, and not a verbatim report of them.*

Mr. Eads said that the two works upon which he had been requested to speak were each of such importance and magnitude as to affect the commerce of the world quite as much as any other enterprise yet undertaken and executed. He then went on to say that for more than forty years many plans for the improvement of the Mississippi had been suggested and tried, but without success. The Mississippi in flood times discharged about 1,250,000 cubic feet of water per second, and brought down in suspension an enormous quantity of sediment. The slackening of the current upon entering the sea caused this to be deposited at each one of the mouths of the delta, so that in front of each a bar was formed. These bars advanced annually into the Gulf, through the additions made to them by the frequent and heavy floods.

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* From London Engineering.

In 1873 the Government engineers proposed to construct a canal forty miles above the mouth of the river to the deep waters of the Gulf. The canal was to be about six miles long, but as the difference in the level of the river and the Gulf is about six feet, it would have been necessary to lock the ships through the canal into the river. He opposed this plan, and urged the improvement of the mouth by means of jetties, and he was so confident of his success that he offered to deepen one of the mouths of the river (on the bar of which only eight feet of water then existed) to thirty feet, and to obtain a depth of twenty feet before any money should be paid to him. The jetty system was opposed on the ground that the sediment brought down by the river was chiefly pushed along on its bed by the current. He, however, contended that it was carried in suspension, and that the quantity which the water was capable of carrying was strictly regulated by the velocity of the current. To disprove this assumption, the opponents of the system quoted the results of careful examinations which had been made at two points of the river by Messrs. Humphreys and Abbot, to show that there was no relation whatever between the quantity carried in suspension and the velocity of the current, according to the diagrams published by Messrs. Humphreys and Abbot, to show graphically the results of their observations. He (Mr. Eads) pointed out, however, that they had fallen into a strange error in comparing the velocity of the current per second with the quantity of sedimentary matter found in a single cubic foot of the water during a second of time. As there was no correspondence between these two quantities, they assumed erroneously that there existed no correspondence between the velocity of the current and amount of sediment carried by it. Their mistake consisted in failing to compare the current per second with the quantity of sediment carried by the entire river during that second of time past the point of observation, instead of that contained in only one cubic foot of water. He took their own tabulated statement of results, and constructed a graphic chart showing the velocity per second and the quantity of sediment carried per second, and the synchronism of the two was completely and thoroughly established, leaving no room for questioning the truth of the principle upon which he founded his hopes of success. Mr. Eads then explained briefly, with the aid of sketches on the blackboard, the location of the bar with respect to the mouth, and showed that as there were thirty feet of water at the point where the banks of the river terminated, and where the river was 1,000 feet wide, the same depth of water could be made to exist 2¼ miles out to sea (where the depth was then but eight feet and the width 5,000 feet), if the volume of discharge were carried out between parallel jetties 1,000 feet apart, over the crest of the bar into the deep water beyond. This was the plan, and it had proved eminently suc-

cessful, for thirty feet of water was thus obtained two years ago, and since that time this depth had been continuously maintained.

Recently a commission of engineers was appointed by the United States Congress to determine the best method of improving the whole course of the River Mississippi, and three plans were proposed to effect this purpose. Thirty thousand square miles of valuable land were liable to annual inundation by the flooding of the river, and this was partially prevented by what is known as the "levee" system—a system of dykes. The advocates of the "outlet system" claimed that if outlets were made, and the flood waters were carried off by other channels to the sea, the height of the floods would be materially reduced. Another system, which may be designated as the low-water treatment of the river, has been tried to some extent, without beneficial results; it looked to the improvement of certain localities and parts of the river where the bars were most troublesome, but no permanent benefit could be secured by these systems, for reasons which he (Mr. Eads) then proceeded to give. A profile (section) was drawn upon the blackboard, the base-line of which represented the level of the Gulf of Mexico, and rising from this, more and more rapidly, a second line showed the slope of the river surface in flood time, and indicated the fall of the river from the higher to the lower level, by which the current of the stream was produced. He then went on to say that the chief element which resisted the flow of the current was the friction of the bed of the stream. The friction of water flowing through pipes or over the beds of streams increases with the increase of the surface in contact with the water, and does not follow the same law as solid bodies. The frictional surface in a pipe of four feet diameter would only be four times as great as that in a pipe of one foot diameter, but as the larger pipe would contain sixteen times as much as the smaller, the ratio of friction to volume would only be one-fourth as great as in the smaller one. It is easily perceived, therefore, how the flow of the river is retarded by the wide places existing in its bed where the friction is so much greater. Hence to maintain sufficient velocity to carry the sediment on to the sea, it must have a steeper slope at these wide places. He called attention to the fact that for the last 240 miles of its course the river was comparatively uniform in width, and the fall was less than two inches per mile, while in the next sixty-nine miles above it was nearly twice as great, and from this point to Cairo, 1,100 miles from the sea, the fall was much greater; this was due to the great number of wide places and islands which existed in that part of the river, and if these wide places were reduced and made narrower, there would naturally be much less frictional resistance to the current, which being then accelerated would be enabled to carry off a much larger quantity of sedimentary matter, which would be taken up by the stream from its own bed, for the

river flows over a bed formed of its own deposits. Every particle of sand lying in the bed, whether deposited yesterday or ten thousand years ago, was brought there by the action of the stream, and was left because of the inability of the current to carry it further. It was evident that as soon as a stronger current touched this deposit it would be again taken up and borne onward to the sea. No engineer is able to permanently increase the velocity of the Mississippi; its normal velocity is that which enables it to carry its burden of sediment without loss or gain, and if accelerated beyond this, the quantity which will be taken up by the stream from the bed of the river will deepen the latter in exact proportion, and as this is made deeper the slope of the surface will be reduced. The dykes were now needed to prevent the floods from overflowing the banks. The contraction of the wide places, and the creation of uniformity of width in the river will lessen the friction, increase the velocity, scour the bed deeper, and thus not only remove the shoals, but lower the slope and render the dykes useless. This was the system of improvement which he had been urging upon the country for five or six years, and it had been finally adopted by Congress; last session a large amount was voted to commence the construction of the initial works of the improvement. He had declared several years ago that the relation between the velocity of the current and the quantity of sediment carried in suspension was purely the result of the expenditure of force, and that no part of the force required to hold this sediment in suspension could be made to perform any other duty without leaving less force in the current to suspend the sediment; and that if a fishing net were drawn across the stream the friction of it would absorb sufficient force to cause the deposition of sedimentary matter below it. This experiment had in fact been tried in the Missouri River, and at the present time one of the means of building up banks to lessen the breadth of the river was by screens made of wire, with meshes one foot square, which were held across the bed of the river by bags of stone, and kept in vertical position by empty barrels secured to the upper edge of the screen. As much as sixteen feet of deposit had been raised in one season of flood by this method. By using willow or wire screens the formation of new banks can be accomplished where the river is too wide, and in the course of a few years comparative uniformity in width may be attained. As the friction increases with a diminution of volume, it is plain that by abstracting a portion of the volume through outlets and draining off the flood water to the sea, the remainder of the river must flow more sluggishly because of the increased ratio of friction. Additional deposits would therefore be thrown down in the bed of the stream, and its surface slope would be increased, thereby rendering higher dykes to prevent overflow a necessity; but by confining the flood water within a uniform high-water channel all the force of the current was

conserved, the ratio of friction decreased, and a lower surface level is the inevitable result.

Mr. Eads then proceeded to the second portion of his address, and spoke of the projected ship railway as follows:

He would not occupy the attention of such an intelligent audience with any argument to show the importance of a route across the American isthmus, but would call attention to the map of the isthmus. No doubt many persons would be surprised to learn that the isthmus between the two continents of America was 1,500 miles in length, or about two and one-half times as long as Great Britain. It lies in the direction in which ships have to sail in the Pacific Ocean when going to the Orient, Japan, California, Oregon, the British possessions, etc.; hence, if they cross the isthmus at Panama, which was near to the South American continent, they would have from thirteen to fifteen hundred miles to sail along the Pacific coast before they came to Tehuantepec, where the isthmus joins the North American continent. It is at the latter point that the ship railway is to be constructed, so that a ship sailing from New York to San Francisco, for instance, would save by crossing at this point about 1,500 statute miles, which would otherwise be necessary if the journey were made through the canal which Count de Lesseps is now constructing. The commerce from the Mississippi, if compelled to pass through the canal on its way to China or California, would have to go nearly twice the length of the isthmus, adding about 2,200 miles to its route.

He stated that Mexico had granted a remarkably liberal concession to aid the construction of the ship railway, and had given the company the right to obtain the aid of any foreign government, and in consideration of this assistance the company was authorized by the terms of the concession to discriminate in favor of the commerce of such government against that of all other countries except Mexico.

Mr. Eads then explained that the first thing to be done in the ship transit would of course be to take the vessel out of the water and place it on the railway. He believed that the oldest plan known for doing this was by the method called in England the slipway, and in the United States the marine railway. This consisted simply of an inclined plane and rails on which a platform was lowered down into the water until it had reached a sufficient depth for the vessel to be floated over it; supporting blocks were then drawn under the various parts of the keel and bilges requiring support, and when this was done power was applied to the platform, which was drawn with the ship upon it out of the water.

He would not discuss the question of the capability of the ship when fully loaded to bear this operation without injury, because numberless ships had been taken out of the water with their cargoes without injury to either, both in this country and in America; and further-

more, he had the assurance of the ablest ship-builders of the world, that there was no danger in the proceeding. He believed that the simplest and most expeditious method of raising the ship would be by that known as the hydraulic dock system, an excellent application of which was to be seen at Victoria Docks, London, made by the eminent engineer, Mr. Edwin Clark. By this method a platform is suspended between a number of upright hydraulic jacks, on which platform is a section of the railway track consisting of twelve rails. When raised, this section of rails would form an extension of the ship railway. The cradle for carrying the ship is run on to this platform, which is then lowered down into the water by means of the hydraulic apparatus to a sufficient depth to float the ship over the car; an automatic system of supports is then drawn under the ship into the position necessary to properly sustain it. The platform is then raised until the rails upon it coincide with those of the permanent way on shore; locomotives being then attached, the ship is hauled across the isthmus.

On the black-board Mr. Eads sketched the wheels of the freight cars as used in this country and in America, and drew attention to the large space between the wheels of each car, in which other wheels might be placed to carry additional burden, if the curves of ordinary railways did not preclude their use. The weight of a ship, however, being more concentrated than that of a train of wagons, it was necessary to have the load carried by wheels placed closer together; and hence it was impracticable to have curves in the proposed ship railway. This must be constructed absolutely straight. Where it became necessary to alter the direction of the route it was done by means of turn-tables, on which the locomotives and car could be easily turned into the direction required. The surveys of the Isthmus had shown that only two, or at most three, of such turn-tables would be required, and they had further shown that the steepest gradients would not exceed one foot in one hundred feet, and that these would only extend through one-sixth of the total length of railway, the others being not more than twenty feet to twenty-five feet per mile. The wheels to be used would be about twenty-six inches in diameter, and would be placed about three feet apart. He had been told by the resident engineer of one of the largest English railways that some of the locomotives in use on that line imposed a weight of nine tons on each wheel when at rest. It was clear, therefore, that five tons could be safely borne by each one of the car-wheels of the ship-railway. If one of the large steamers, 450 feet in length, running between Liverpool and New York, were to be transported, she would require a car not larger than 400 feet; one rail would therefore have about 130 wheels upon it, these wheels would bear 650 tons, twelve rails would therefore carry 7,800 tons. The rails would be placed four feet eight

and a half inches apart (standard gauge), and would cover an area fifty feet in width; this multiplied by 400 feet would give 20,000 superficial feet of ground to sustain the ship, or, in other words, there would be a pressure of 780 pounds per square foot on the ground. This is less than the weight imposed by a brick wall only one story high; but to further illustrate this he would give them a more familiar example which all had doubtless frequently observed, viz., that of a horse trotting along a common road in the country. With its rider it imposed a pressure of about 1,200 pounds upon the road, yet scarcely left the imprint of its shoes upon it. This weight was sustained on an area of about 24 square inches, because the entire weight of horse and rider came alternately upon two feet only. The horse's shoes are not more than about 12 square inches each, and thus imposed upon about one-sixth of a square foot a weight of 1,200 pounds, or nearly ten times the weight per square foot, which the heaviest ships would bear upon the road-bed of the ship-railway.

It is evident, also, that if the rails which are used in this country for a first-class railway are sufficient to bear nine tons per wheel of a locomotive running at fifty to sixty miles per hour, they would be amply strong enough to bear a pressure of five tons imposed by the wheels of the ship-railway car.

This would give some idea of the great economy with which the permanent way of a ship-railway could be constructed in comparison with the cost of digging a canal. Of course, a first-class permanent way would be a necessity, but this being once constructed, its maintenance and repair would be much less than that of a canal across the Isthmus, for the simple reason that the rains in Panama are torrential in character, and the amount of detritus washed into the canal would be enormous.

It would not be necessary to keep the rails absolutely true and level, though it would be bad management and neglect to allow an irregularity equal to one inch in their respective levels to occur, but even this would cause no injury to the car, inasmuch as each wheel would be independent of its fellows, and would have one or more strong spiral steel springs over it which would permit it to rise three inches without injury. The entire car would actually be carried upon a mass of steel springs to allow for any inequality in the permanent way.

He had been informed that the ordinary price charged to customers by railways in England for the carriage of coals was one farthing per ton per mile; if it were to cost double this to haul loads on the ship-railway, it would still leave a large margin for profit; and he had been informed only a day or two previously, by a ship-owner engaged in carrying wheat from California to Liverpool, that the current price of freight in San Francisco was then equal to ½d. per pound, and that he could well afford to pay one-third of the freight to have his car-

goes transported across the Isthmus of Tehuantepec, and thus save 8,250 statute miles which is now required to round Cape Horn.

The weight of the ship is about half that of the total cargo, and the weight of the railway car, on which the ship would be carried, would not exceed one-eighth of the total weight of the ship and cargo, so that there would be about 40 per cent. of non-paying load to be hauled, which is considerably less than the proportion of non-paying load on ordinary railways, which is often as much as 50 per cent., and rarely falls below 40 per cent.

MONITORS AND TURRETS.

LETTER.

To the Editor of the Missouri Democrat.

St. Louis, June 4, 1867.

Permit me to correct a statement made in the *Democrat* of this morning, with reference to a proposal made by me to the French Government through Mr. Wm. H. Webb, the eminent naval architect and constructor of the *Dunderberg*, which vessel has been sold to France.

The *Dunderberg* has, I am informed, two fifteen-inch guns mounted on carriages designed by Capt. Ericsson, and has port-holes for others not yet mounted.

Mr. Webb has been authorized by me to propose to the proper French authorities to mount two fifteen-inch guns on the *Dunderberg* on my carriages, on the condition that the carriages are only to be paid for provided they are equal in every respect to Mr. Ericsson's, *besides being able to load and fire the guns on them twice as rapidly*—not as you have stated, "once in two minutes." I have no doubt of being able to fire the fifteen-inch gun once every forty-five seconds, if the proposition is accepted; or five shots (if not more) to every one fired from the gun on the Ericsson carriage.

Your obedient servant,

James B. Eads.

In this connection it is proper to mention that in a private letter to Mr. Eads the Secretary of the Navy uses the following language:

"Wise tells me that you have achieved a wonderful success in your gun-carriage, and Fox gives me the same account. I congratulate you most sincerely, and trust you may be rewarded for your invention, and the great service you have rendered not only in this, but other respects to the country."

LETTER

To the Editor of the Army and Navy Journal.

Sir: I trust you will do me the justice to publish this reply to the strictures contained in your article on the Turkish iron-clad *Moyini Zaffer*, on page 190 of your present volume.

It is well known that after the discomfiture of the monitors in their first attack at Charleston, a loose, heavy base ring was placed around their turrets to protect the joint at the deck from such injuries as were received in that action. A similar ring was ordered to be placed around the monitor turrets then building. A list sent me from the Navy Department contains the names of thirty-nine monitors on which this ring was fitted; and the first name on it is that of the *Dictator*. It includes, also, all the monitors of the *Monadnock*, *Canonicus*, *Passaic*, and *Yazoo* classes. It is, therefore, a distinctive feature of the monitor system, and I was justified in discussing it as such in my report to the Secretary of the Navy. I had no right to believe this ring would not be put on the *Dictator* until after sad experience should prove the need of it; but as you assert so positively that she has none, I will admit your statement, and confess that she is more vulnerable than I represented her. Whether, however, there is an exceptional monitor without this band, or not, does not affect the proposition I advanced.

I stated that the base ring was but a partial remedy for an inherent defect in the monitor system, and asserted, in substance, that if the iron in it were used to unite the turret walls and deck frame firmly together, the ship would be more capable of resisting both shot and storms. This advantage the proposed system of fixed casemates or turrets would possess over the monitor system. Your whole answer to this proposition is your exclamation that "the *Dictator* has no band around her turret, and was never intended to have one!" If your article was written by an expert, such a subterfuge would be discreditable. No one can read my report (or the two paragraphs on this point) without seeing that the monitor system, and not the *Dictator* was under discussion, and that the turret of the *Dictator* was simply used to compare that system with the one proposed. Your assertion that "it was never intended for her to have one" is no evidence that she has none now, for it was never intended for the others to be thus protected until the lesson at Charleston taught the need of them.

After crediting that monitor, from which the public have been led to expect so much, with a greater degree of resistance than you say she possesses, I think your readers will be surprised in this instance at the complacency with which you claim to have "exposed the misstatements that have been published relative to the monitor system."

I was not, as you say, ignorant of the fact that the *Dictator's* turret rests wholly on its four inner courses of plating. Nor did I state, as you would make your readers believe, that her turret could be stopped by a shot swelling her turret plates downward to the deck. I did not mention the name of the *Dictator* in that connection, but said this was one of the accidents to which the monitors were liable. In the *Dictator's* case, without the base ring, it is only necessary that a shot striking at this unprotected joint should depress the two one-inch deck plates at its base a few inches, to insure the projectile or its *debris* stopping the rotation of her turret. The base ring, in addition, would be but a partial protection against such a disaster, as the following extract from the report of Commander Simpson, of the *Passaic*, will show. (See page 259 of Report of Secretary of the Navy on armored vessels):

"The base ring as now attached to the turret prevents injury to the bottom of the turret itself, but the liability of stopping the revolution of the turret, by forcing the iron down to the deck plates, is just as great as ever. In a late action in this vessel, owing to this cause, it required at one time thirty-four pounds of steam to revolve the turret, until melted tallow was squirted in from the outside; and had it not been for the elastic character of the packing under the plate below the ring, the turret would inevitably have stopped. I have also had two shots that penetrated the deck directly under the ring. If the base of the turret were carried down below the spar deck, it might be so inclosed as to prevent the rush of water into the vessel through the opening between the turret and deck, as at present. The composition ring under the turret does not perform the work required of it. After the turret has been struck several times at the base, this ring ceases to act independently and attaches itself to the turret, becoming a part of it, and rises or falls or revolves with it. It is also found to be dangerous, as the flange inside the turret is broken by the force of the blows on the base. The extra base ring does not prevent this effect, for in this vessel there are three pieces of the flange broken off, one or two of them as much as four feet in length."

The difficulty of rotating the turret of the *Miantonomah* in a seaway, on her late visit to Europe, the frequency with which this embarrassment occurred in action during the late war on other monitors, and the fact that the base ring does not entirely cure the trouble, will, I think, convince the impartial reader that a corps of tallow squirters, to operate outside the turret when engaging an enemy, must become no less a necessity of the monitor system than the base ring, in the event of another war with an enemy possessing heavier ordnance than the 10-inch round shot and 6-inch rifle projectiles of the Confederates. On this point, at least, on the score of

economy alone, I am sure you will agree with me that the advantage is in favor of the fixed system.

You say the apprehensions expressed in my report with reference to the rotation of the turret being stopped by injury to the joint at the base of the pilot house, show that another very important fact "had been overlooked, viz.: that the turret is projected considerably above said base in order to protect it." The following extracts from the reports of officers on the monitors will show how efficient this protection, which I am charged with having overlooked, proves to have been. On page 73 of armored vessels, Commander John Downes, of the *Nahant*, says:

"At 4:30 the turret refused to turn, having become jammed from the effect of three blows from heavy shot, two of them on the composition ring about the base of the pilot house (one of them breaking off a piece of iron weighing seventy-eight pounds from the interior that assisted to keep the house square on its bearings, throwing it with such violence to the other side of the house, striking, bending and deranging the steering gear in its course, that it bounded from the inside curtain and fell back into the centre of the house)."

By this accident one man was killed and another struck senseless in the pilot house. On page 63 (armored vessels) Capt. John Rodgers, of the *Weehawken*, states:

"At one time the turret revolved with difficulty in consequence of a shot upon its junction with the pilot house, but it worked well after a few turns had been made with higher steam."

You state that my fears that the pilot house may be lost overboard, or the rotation of the turret be stopped by the impact of shot possessing sufficient power to overcome the inertia of the pilot house itself, "held in place by a wrought iron shaft 14 inches in diameter and weighing 80,000 pounds, will amuse our young friends at West Point and the Naval Academy." I fear that they will scarcely thank you for believing them so verdant as to accept ridicule for argument; and when the following account of the effect of a half-spent 6-inch ricocheting rifle-shot on a 24-ton monitor pilot house is perused by your older readers, they will be amused at your essaying to tax other people with being "evidently ignorant of the most important facts" connected with the monitor system. Captain Drayton, of the *Passaic*, says (page 61, armored vessels):

"A little after, a very heavy rifle shot struck the upper edge of the turret, broke all of its eleven plates, and then glancing upward took the pilot house, yet with such force as to make an indentation of two and a half inches, extending nearly the whole length of the shot. The blow was so severe as to considerably mash in the pilot house, *bend it over*, open the plates and squeeze out the top, so that on one side it was lifted up three inches above the top on which it rested, exposing the inside of the pilot house and rendering it likely that the next shot would take off the top itself entirely."

I will not trespass further upon your columns by quoting from the official reports of the department, but in proof of what I asserted respecting the liability of the guns being disabled by the bending of the gun slides, from the effect of shot upon the turret near the extremities of the latter, I will refer you to the report last quoted from, which gives an account of one gun being rendered useless by this cause, on the *Passaic*, and also to page 69 (armored vessels), where Captain Fairfax, of the *Nantucket*, states that after the third fire from the 15-inch gun it was rendered useless by the jamming of the port stopper from the enemy's shot bulging in the turret plates; neither of which results could have occurred if the guns had been protected by a fixed casemate on the system proposed in my report. In the first case the gun slides could not have been affected, and in the last, the gun could have been used at another port.

Your strictures prove that you did me the honor to examine my report; how, then, can you justify yourself for stating that you "know of no other reason" why the fixed battery is advocated "than the assumption that the joint between the rotating turret and the deck cannot be made secure?" If you had read my report with any other purpose than to object to it, you would have stated the additional reasons given in it for not supporting the rotating system, chief among which is that the fixed system recommended in it gives a more seaworthy vessel; more thoroughly protects the machinery within the turrets; gives greater economy of armor; less danger of disabling the guns; a more rapid use of them (because they can be turned without turning an immense weight of armor); admits of equally simple devices for working the battery, with entire command of the horizon, and affords greater facilities for the escape of the crew in cases like the loss of the *Monitor*, the *Weehawken*, and *Tecumseh*. You could also have stated, if your object was to give your readers impartial information on the subject, that the drawings accompanying the report are drawn to scale, to enable the fact to be proven by them, that four 15-inch guns can be protected on this system (including smoke stacks), with an equal thickness of iron, with a saving of 32 per cent. over the monitor system, and that when an equal amount of armor is used, the port sills can be placed five feet and eight inches above the deck, or exactly twice as high as the *Dictator's*. These are facts which I think you cannot disprove.

Fully appreciating the courtesy which grants this opportunity of vindicating myself in your columns,

I am, sir, your obedient servant,

JAMES B. EADS.

St. Louis, December 4, 1869.

LETTER

TO THE EDITOR OF THE ARMY AND NAVY JOURNAL.

ST. LOUIS, January 29, 1870.

SIR: Your editorial contributor of the article published in your journal on the 1st of January, and entitled "Rotating and Fixed Turrets," seems to know that the defects of the monitors are becoming so well understood that their claim to be considered *invulnerable* cannot be supported either by their record or by the intrinsic merits of their design. He evidently thinks but one way is left to save the system from public disfavor, and that is by clamoring about the ignorance of those who have the temerity to doubt its superiority over every other.

Your contributor makes no denial of the justice of my criticisms when applied to the monitors provided with *base rings*, supported as they were by proofs from official reports; but admits that "the original small craft which served us so effectually during the war, possessed defects which, in later structures, have been nearly overcome, and which, in future structures, may be wholly removed." He says, "these cardinal objections, urged on Mr. Eads' system of naval defence, are wholly groundless as regards the *Dictator*. It was not this vessel, it appears, but the original batch of small monitors, which Mr. Eads criticised," and tells us "that these objections have been removed in the *Dictator* and *Puritan* classes, and consequently in the *Kalamazoo* class of turrets." He says: "The *base ring* which was attached to the small monitors because the thin turret-plating was found inadequate, a matter to which Mr. Eads devotes much space, we deem it waste of time to discuss. All that need be said is that the *Dictator* and *Kalamazoo* class of turrets *were built* [these *italics* are mine] on a plan requiring no ring at the base."

From these extracts it is evident he abandons the attempt to defend the vessels provided with *base rings*. These constitute the *Monadnock*, *Canonicus*, *Passaic* and *Yazoo* classes, nearly forty monitors, all of which he leaves *hors du combat*, and concentrates his entire energies in defending the monitor system with the turrets of the *Dictator* class, the *Puritan* class and the *Kalamazoo* class. I therefore leave "the original batch" to survey the field occupied by these invincibles. How many remain, then, of those undemolished and acknowledged representatives of the monitor system? Will your

readers, after all this ado about how our *Kalamazoo* class of turrets "*were built*," and all the bombast about the *Puritan* class, and the *Dictator* class, credit the fact that, excepting the *Dictator*, there is not at this time, and never has been, a turreted vessel of either class in existence?

I once read of an urchin at school (not one of "our young friends at West Point and the Naval Academy") who, having his coat closely buttoned up, was asked, "Where is your shirt?" "Mother is washing it." "Have you but one shirt?" continued the astonished interrogator. To which the indignant lad replied, "Would you expect a body to have *a thousand* shirts?" When your contributor is asked, "Have you but one of these wonderful vessels?" I can imagine his indignation as he replies, "Would you expect a body to have *a thousand Kalamazoos?*"

I shall not quarrel, however, with him because of the paucity of his *Kalamazoos*, but will briefly proceed to examine the merits of his last remaining hope—the *Dictator*. I will first state, however, that the turrets of the *Puritan* and the *Kalamazoo* classes, which he takes so much pains to tell us "*are composed* [my italics, again] of two distinct cylinders of plate-iron," have never been constructed at all.

The department is even now maturing plans for completing, as casemated ships, the vessels constituting these classes, which were commenced several years ago, and before the defects of the *Dictator* were fully manifested. I am informed that it has already decided to do this with the *Kalamazoo*. The fact that their turrets were once contracted for, and that the department compounded with the contractors and cancelled the agreements while the work was in progress, together with its subsequent course in the premises, would seem to prove its want of faith in the system; but this will doubtless be all explained by your contributor. The motive which prompted him, however, to endeavor to lead the public to believe these turrets "were built" and "are composed," etc., when they are not yet built, together with certain questions of ethics, to which the use of these deceptive phrases gives rise, I leave for him to settle with your readers, while I proceed to examine the merits of the *Dictator*. The impregnability of the joint between the base of the pilot-house and the turret roof of the *Dictator* is thus set forth by your contributor: "We stated in our article that shot could not strike the base of the pilot-house of the *Dictator*, because the turret wall of that vessel (we might have added, the turrets of the *Kalamazoo* class) is carried to such a height that shot cannot thus strike." The top of her turret wall is 26½ feet in diameter. The pilot-house, placed in the centre of it, is not over ten feet. This leaves about eight feet all round from pilot-house to turret wall. The turret wall of the *Dictator* is projected only six inches above the turret roof, consequently a roll of the ship

of four degrees would bring the top of the turret wall below the level of the base of the pilot-house.

This protection would then cease to exist against shot moving in that horizontal plane, and this plane would be no higher than the guns of several English iron-clads already afloat. To make this boasted protection available against them at short range, it would be necessary that the contest be fought on a perfectly smooth sea. Even in such a sea, this six-inch belt would be too low to protect this joint against their guns if they were only a few hundred yards distant, for the elevation of three or four degrees required by the distance would so increase the curvature of the trajectory of the shot as to insure its passing over the turret wall, it being only high enough, when perfectly level, to intercept projectiles intersecting the line of fire at an angle of less than four degrees. In attacking forts it must be manifest that this joint would be exposed to the direct fire of any gun four degrees above it. Even in a calm sea, a gun on a level with it, or even below it, would command this joint if it were sufficiently distant to require a few degrees of elevation to maintain the trajectory above the line of fire to the requisite distance. It is therefore ridiculous to claim that this joint is impregnable against fortifications. To make it at all available against an enemy afloat involves the necessity of a smooth sea, and of the *Dictator* selecting and maintaining her own position in the fight. As she is known to be a complete failure in point of speed, making only seven knots per hour, of course this would be impossible with almost any English iron-clad afloat, none of which have a speed of less than nine knots, while several go at thirteen or fourteen. It is therefore evident that this six-inch belt projected above the turret roof is too insignificant a defence of the joint to merit serious consideration. My apology for devoting so much space to it is that it is claimed to be so important. If it must continue to form a characteristic feature in the monitor system, it is essential for the advocates of the system to insist that the rules of the prize-ring be adopted in naval engagements, and that it be expressly understood that hits on the pilot-house below the belt shall be unlawful, and will entitle the monitor to claim the stakes.

Your contributor maintains that it is impossible for any heavy projectile to disturb the inertia of the *Dictator's* pilot-house, weighing eighty thousand pounds, and held in place by a fourteen-inch spindle. He asserts, therefore, that it would not be bent over, and thereby endanger the rotation of the turret beneath it, nor be liable to be lost overboard by the fracture of the spindle. In support of my assertion to the contrary, made in my report to the Secretary of the Navy, and ridiculed in your contributor's articles on the *Moyini Zaffer*, I quoted the report of Captain Drayton, of the *Passaic* (page 61, "Armored Vessels"), and proved by it that a half-spent riccocheting rifle shot (after breaking all of the eleven one-inch plates of the upper

part of her turret) had sufficient force left to "mash in the pilot-house" and "bend it over."

To avoid the inevitable conclusion that a direct blow from a heavy projectile can *bend over* and disable the forty-ton pilot house on the *Dictator*, if the shot described by Capt. Drayton could bend over the twenty-four ton pilot house of the *Passaic*, similarly secured, this able physicist gravely tells your readers that "the commander of the *Passaic* had no idea of saying that the *pilot house*, as Mr. Eads appears to suppose, had bent over: the top of the wall had simply bent over by the effect of a glancing shot," and thinks "This singular error of Mr. Eads has probably been noticed by our young friends at West Point and the Naval Academy." Capt. Drayton said: "The blow was so severe as to considerably mash in the pilot house, bend it over, open the plates," etc. These young gentlemen will probably think that, as Capt. Drayton had already said the pilot house was considerably "mashed in," it was surplusage to state in the same sentence that "the top of its wall had been bent over" also. Yet this is what your contributor would make them believe he meant to say. It is probable there are not twenty students at the Naval Academy who could not have told this conscientious writer (what he was evidently ignorant of), viz., that the report of the Commission appointed by Mr. Welles to examine and report upon the injuries to the *Passaic*, and published on page 83 of "Armored Vessels," would cover him with confusion for this attempt to distort the plain meaning of a gallant but deceased sailor. For the *words* of Capt. Drayton are fully corroborated in that report. This commission (composed of Capt. J. C. Rowan, U. S. N., Charles W. Copeland, George W. Quintard, M. F. Merritt, and Jos. J. Comstock) states that the shot in question "raised the pilot house half an inch and *started it over on one side*, breaking two bolts in the pilot house." The italics are my own; the words are those of the report.

Your contributor merits all the glory he has gained by this attempt to destroy the effect of the gallant Drayton's words, in this effort to sustain the ridiculous proposition that the inertia of forty tons of iron can not be disturbed by a cannon shot of such weight and velocity as was known to be practicable at the date of the *Dictator's* construction. Arguments based upon such absurdities must require unusual expedients to sustain them. If he still doubts that this comparatively light shot did really overcome the inertia of a twenty-four ton pilot house, after being told by one witness that it *bent it over*, and by five others that it *raised it half an inch and started it over on one side*, I can give him no other official proof of the power of shot to move monitor pilot houses.

Being engaged from the inception to the close of the rebellion in designing and constructing armored vessels, I was kept promptly and confidentially advised by the Department of "the most important

facts" connected with the performance of the monitors and other ironclads, and although charged by your contributor with being ignorant of the subject, may be able to refer him to some other reports that will also be new to him.

Your contributor lays great stress upon the fact that the gun slides of the *Dictator* do not touch the turret wall, and consequently the disabling of the guns can not occur from shot striking opposite their ends.

The Commission before referred to, speaking of an accident of this very kind, by which one of the *Passaic's* guns was rendered useless, and certain damages done to the joint at the base of the turret, says: "We would take the liberty of suggesting that this form of injury may hereafter be guarded against by fastening a very heavy ring or band around the base of the turret, to prevent distortion, and leaving sufficient freedom between the rails of the carriage and the turret, so that any slight distortion of the turret will not affect the gun carriages."

It appears that the suggestion of this intelligent Commission was not deemed large enough for the entire monitor navy, for we find only one-half of it used on "the original batch," and the other in the *Dictators*, *Puritans*, and *Kalamazoos* that "were built" on a plan not requiring a base ring. The originals had the ring with the long gun slides, and the last three classes the short gun slides without the rings.

It seems not to have been noticed that one of the chief objects of this practical Commission, in recommending the use of a heavy band around the base of the turret, was to prevent the *distortion*, which those gentlemen foresaw was likely to occur to it if robbed of the eight important points of support in its circumference furnished by the four gun slides, which are placed about four feet apart in the base of the turret, and transversely over the main turret beam through which the vertical spindle passes.

When these should no longer touch the turret wall, it would have nothing except the ends of the main beam, bolted to its base at two opposite points in its circumference, to preserve its circular shape at the deck. These gentlemen doubtless thought that the turret would then be likely to lose the cylindrical and assume "the partially oval form," if struck by even as small shot as that which mashed in the *Passaic's* pilot house. But they were merely "superficial observers," and had not been taught by your contributor that "a partially oval turret would work upon a broad flat ring as well as one that is cylindrical." They probably thought that a heavy shot at the base might bend the bottom of the wall in without moving the top of it in also, and thus cause an ugly leak, even if it did not stop the turret's rotation, and that its "distortion" might, to some extent, be guarded against by a heavy base ring.

The *Dictator's* turret is twenty-four feet in its internal diameter. Its wall is fifteen inches thick, and it is not enlarged or in any way strengthened at the base.

The turret walls of "the original batch" were eleven inches thick. The bands placed around their bases were five inches thick by twelve or fifteen inches in height. Including this band, those turrets are consequently one inch thicker at the base than the *Dictator's*.

The *Dictator* has a series of similar five-inch bands, one above the other, incorporated into the construction of her turret, the lower one of them being six inches thick (one of the ten thin plates being cut short to allow for its extra inch of thickness). In my letter I proved from official reports that the base ring about the monitors failed to give adequate protection. The heaviest shot thrown against them were from ten-inch columbiads. These shots weighed only 128 lbs. Yet they were found sufficient to disable a turret sixteen inches at its base, including the base ring. Now, is it not a most egregious absurdity to claim that the *Dictator's* turret, not as thick at the base by one inch, is invulnerable against fifteen-inch shot weighing three and one-half times as much?

And is it not equally absurd to claim that this wall, resting on a flat, level surface, and in no way secured from being knocked into "a partly oval shape," except at only two points in its entire circumference of eighty-three feet, should have sufficient stiffness and inertia to prevent its being distorted more than two inches? For two inches is the entire distance existing between the turret wall of the *Dictator* and the ends of her gun slides. This enormous space of two inches is the basis upon which their claim to impregnability is resting. The feeling of security which possesses your contributor on the gun-slide question can only be equaled by the ostrich, who, having thrust his head under cover a few inches, thinks everything is then absolutely safe.

Your contributor says: "Critics all point to the disastrous consequences of shot striking at that junction; [the base of the turret;] but they do not appear to comprehend the practical merits of the expedient of rotating the turret on a flat ring, level and parallel with the deck." Of course they do not, without a great deal of study, because it is such a very intricate and difficult problem. It might be worked out, though, by the imaginary calculus, if it failed to be solved by the differential or integral. Equally incomprehensible is the proposition, to ordinary minds, that the base of the *Dictator's* turret is safer without a heavy ring to prevent its distortion than with it; and that a fixed turret joined firmly to the deck "will, owing to the rigid nature of the connection, inevitably produce fracture and leak" from the impact of a heavy projectile, while the same shot would be harmless against the base of the same turret if it was not joined to the deck, but only stood "on a *flat ring*, level with the

deck," that would allow the turret to assume the oval or cylindrical form, just as the force of the shot moved it. Neither leak nor harm to the gun slides, two inches distant within it, could possibly occur. "Casual observers" fail to see "the practical merits of the expedient," however, and the records of the "original batch" do not quite support these propositions.

One of the great merits claimed for the *Dictator* is her remarkable steadiness in a seaway. "The sea breaks over their low, flat decks powerless to harm," exclaims their enraptured advocate. He might have added, "And their guns are equally powerless," for the *Dictator's* ports being but two feet ten inches above her low, flat deck, they must, of course, be kept closed at such times. In consequence of the small exposure of hull above water, a small quantity of armor will clad her sides, and for the same reason a small amount of leakage will send her to the bottom. If we cannot gain immunity from the enemy, who is rarely with us, without increasing the danger of foundering, which is always present, had we not better take our chances behind thinner armor? Perhaps as suggestive a lesson in the science of naval defence as can be drawn from our late conflict would be a comparative statement showing the actual loss of life on our armored casemated vessels, caused both by the fire of the enemy and the foundering of the vessels, and the loss of life from the same two causes in the monitors. I am confident that, whether this comparison be made according to tonnage, weight of metal thrown in action, cost of the ships, or number of men engaged in them, the loss of life will be found to have been greater on the monitors than on the others; while there is not a sailor afloat or ashore but would deem death in battle far preferable to the fate of those who went down on the ill-fated *Weehawken*.

The overhang of the *Dictator* is another one of the defects of this vessel, though it has been claimed as one of her greatest perfections.

The amount of impenetrability given by this three or four feet of timber backing projecting out from her sides is obtained by a sacrifice of speed which makes her terrible ramming projection at the bow a most ridiculous appendage; for the possibility of using it, the vessel having never been able to make over seven knots per hour, is so funny as to "amuse our young friends at West Point and the Naval Academy." This ram, so curiously wrought, and of length sufficient to pierce the most powerful enemy through and through, is only dangerous to the friendly ship that tows her along, as she goes cruising on the high seas and chasing the enemies of the Republic. A Mormon elder, about to mount a dilapidated steed, was asked what he expected to do with it? On replying that he intended to follow the Lord on him, his interrogator rejoined, "You will have to push that horse right smartly before you overtake him." The

Dictator's chances for overtaking an enemy are nearly as good. Her contract guaranteed a speed of sixteen statute miles per hour for fifteen consecutive hours, but the greatest speed shown by her steam log in the Bureau at the Department, is only seven knots, and that but for one brief hour. "*Sic transit*," &c. As the engine and boiler power of this ship is enormous, and as almost every one of the "original batch" (without exception, I believe,) failed to make the speed guaranteed by their contract, I can only account for the fact, in the *Dictator's* case, by the retarding influence of this peculiar appendage, the *overhang*, coupled with the laborious duty of carrying her dangerous ram.

In summing up the wonderful qualities of this perfect specimen of the monitor system, then, we find: First—That her invulnerable turret never has been under fire. Second—That turrets as thick as hers at the base have been injured at the deck joint with projectiles scarcely more than one-quarter as heavy as 15-inch shot. Third—That her gun slides are only secure against the lighter class of projectiles. Fourth—That similar joints on the turret roof on other vessels have been injured, and the turret stopped by light shot, whilst hers is only provided with an additional protection that is not available except under the most favorable circumstances, and those circumstances beyond her control. Fifth—That pilot houses similarly secured, and only sixteen tons less than the weight of hers, have been wrecked by small and half-spent glancing shot. Sixth—That her low speed is such as to make her a helpless hulk against the submerged rams of many war vessels now afloat. Seventh—That her low ports render her unable to return the fire of an enemy who may chance to overhaul her in a rough sea. Eighth, and lastly—That her low position in the water, and the warning fate of three of her predecessors, give assurance that eternal vigilance is the price of her safety against sudden foundering.

To continue thus persistently to mislead our countrymen into the belief that such a vessel is capable of coping with some of the English iron-clads now afloat, when we dare not trust her at sea alone for fear of foundering, or that we have one single armored ship (*Kalamazoo* or anything else) that can stand against them, betrays either unpardonable ignorance or a total want of patriotism.

I have been reluctantly drawn into this discussion to defend myself against the severity of your personal strictures, and have hastily thrown these facts and arguments together, with no wish to depreciate the important services rendered by the monitors in our late conflict, nor in anywise to lessen the fame of their distinguished inventor. Their merits and his genius will find in history the high place deservedly won by them in the exigencies of the hour, no matter what system of naval defence be found best suited to the present wants of the age.

I have no leisure to notice the ridicule or criticisms which you or others may choose to apply to my system, nor have I the right to ask your space in defence of it, but trust I shall always find time and materials, and have opportunity granted, to repel personal charges of ignorance and misrepresentation, either direct or implied, when made in a journal of respectable standing.

Your obedient servant,

James B. Eads.

SAINT LOUIS BRIDGE.

REPORT

TO THE PRESIDENT AND DIRECTORS OF THE ILLINOIS AND ST. LOUIS BRIDGE COMPANY.

GENTLEMEN,—I have the honor to submit the following report of the operations of the engineering department of your Company.

In view of the great importance of your enterprise, the deep interest manifested in it by our citizens and the public generally, and because the plans adopted by you have been frequently misrepresented and unfairly criticised, I have deemed it proper that everything of interest connected with my department should be placed in such form as to be clearly understood, not alone by your stockholders, but also by every person of ordinary intelligence in the community. I have, therefore, endeavored to explain the plan of structure, the principles involved in its construction, and the reasons for its preference, in the simplest language I can command, and with an avoidance, as far as possible, of the use of all technicalities not understood by every one. At the same time you will be furnished, in an appendix, with all the scientific data, principles and formulæ involved in investigating and calculating the various strains to which each and every part of the Bridge is liable to be subjected. These are so arranged, together with the results deduced therefrom, as to furnish to the most critical and scientific engineer the materials in convenient form whereby he may be able, with great economy of labor, to investigate the correctness of every step that I propose to take in constructing your Bridge.

Fully estimating the great responsibility assumed in undertaking to design and complete this important work, I have felt that in no way could I so certainly insure a successful result, and at the same time manifest my appreciation of the obligation imposed upon me, as by securing the aid of the ablest talent in every department of the work, and proving by careful experiment, as far as possible, everything connected with it that has not been already fully demon-

strated in practice, so that when the whole is finally consummated you can feel assured no step was taken that was not well considered with due regard to the safety, durability and economy of the structure.

The mathematical investigations and calculations for the Bridge were confided to my chief assistant, Col. Henry Flad, C. E., and in this laborious duty he has been faithfully and efficiently aided by Mr. Chas. Pfeifer, C. E. Several months of patient labor have been spent by these gentlemen in the investigation of the arch with spandrel bracings, the ribbed arch with pivoted ends (as in the Coblentz bridge), and with fixed ends, and of various depths. After careful revision by Col. Flad, the results obtained from time to time were submitted to me; and, finally, to guard against any possible error in the application of the principles upon which the investigations were made, or in the results arrived at, they were referred by me to the patient analysis and careful examination of Chancellor W. Chauvenet, LL. D., of the Washington University, formerly Professor of Mathematics in the U. S. Naval Academy at Annapolis. His certificate, affirming their correctness in every particular, will be found appended to this report. For the interest this gentleman has taken in the enterprise, for the care bestowed in examining and verifying the scientific data required for the work, and for many valuable suggestions and simplifications in the investigation, I feel under many obligations.

It gives me great pleasure also to state, in this connection, that Chancellor Chauvenet, whose eminent ability as a mathematician is known and acknowledged throughout Europe as well as America, accords high praise to Col. Flad, and also to Mr. Pfeifer, for the correctness and ability shown by them in discharging the important duty confided to them.

LOCATION.

As the cost of the Bridge, its revenues, and the public convenience are greatly affected by the location of the structure, I have given this subject the utmost consideration. To aid me in the solution of this important question, I called to my assistance, with your permission, Mr. R. B. Lewis, C. E., a gentleman of great experience and high reputation as a locating engineer, and for many years in the service of the Pennsylvania Railroad. He is now President of the Broad Top Railroad and Consulting Engineer of the St. Louis and Vandalia Railroad. For his valuable aid and advice I feel greatly indebted. His opinion, and that of my entire corps of assistants, after a thorough examination of the subject, was unqualifiedly in favor of the location at Washington avenue, which location was formally adopted by the Board of the St. Louis and Illinois Bridge Company, and, since the

consolidation of the two companies, by the board of the consolidated company also.

When considered with reference to the cost of the structure, the location at Washington avenue commends itself, because at this point the river is narrower than at any other place opposite the city. It is nearly two hundred feet less than at the location selected for the bridge designed to be built by Mr. Boomer, and is 580 feet less than at Venice (opposite the northern part of the city), where the location has been urged as more suitable for railroad purposes. As the Bridge proper must at either of these two places be longer than at Washington avenue, and as there can be no saving in the cost of its approaches or foundations at either locality over the one selected for it, either one of those locations, if selected, would result in an inevitable increase in the cost of the Bridge. I am not unmindful of the fact that the cost of the tunnel, in connection with the location at Washington avenue, is advanced as an objection to this selection.

The location selected for Mr. Boomer's bridge, a few blocks above Washington avenue, contemplated the running of steam trains across Broadway and other great thoroughfares, and out through Cass avenue. The tunnel is no more a necessity at Washington avenue than at the latter location. A grade of thirty feet to the mile would bring the trains from the centre of the centre span on your Bridge to the level of Washington avenue at Third street; and our citizens would be just as likely to permit them to traverse that avenue above ground as they would the route designed for them at the other location. It is preposterous to believe that the city would permit steam trains to pass over either route above ground, both being through portions of the city densely populated, and both crossing the same great thoroughfares. At either location a tunnel is a necessity for unobstructed railway traffic. A tunnel in connection with the Boomer location would necessarily be longer than at Washington avenue, and would therefore cost more. As the cost of your tunnel cannot exceed $400,000, and as the Company will be entitled to charge tolls on trains passing through it, that part of your investment must prove profitable, and is therefore unobjectionable.

Washington avenue is the centre of population of the City of St. Louis. It is a spacious and elegant avenue, dividing the city into two nearly equal portions of territory. The city front on the river extends three and three-quarter miles below the foot of this avenue and three and one-quarter miles above it, thus nearly equally dividing the seven miles of wharf or river front that forms the eastern boundary of your city. The grades upon this avenue are of the gentlest character, from its western end to Third street. From this point the carriage-way of the Bridge will form a continuation of the avenue to Third street in East St. Louis. In the latter city the eastern approach to the Bridge will commence at the intersection of Crooks and

Third streets. Vehicles starting in East St. Louis on Crooks street at Fourth, to cross the Bridge, will reach the top of the eastern abutment by ascending a grade of but five feet rise in one hundred. After crossing the Bridge to the western abutment, the grade of the carriage-way is perfectly level to the intersection of Third street in St. Louis. Here the wide and level avenue will form a most convevient outlet for the vast tide of travel constantly crossing the Mississippi. The intersection of Washington avenue by streets at right angles to it, every three hundred feet, will greatly facilitate the exit and entrance of teams and passengers from and on to the Bridge. Two of these streets (Fourth and Fifth) are each eighty feet wide.

The carriage-way of the Bridge will be of sufficient width (thirty-four feet) to accommodate two vehicles going abreast in each direction, and will have a double track for horse railways laid through its centre. On each side of the carriage-way will be a foot-path eight feet wide for pedestrians. Convenient stairways will be provided on the wharf on each side of the river, and at Main and Second streets, for entrance to and exit from the Bridge.

When we consider that one-half of the people of St. Louis reside north, and the remainder south, of Washington avenue; that it divides the territory of the city into two nearly equal portions, and that teams and passengers can enter and leave the Bridge with such ease at either end of the structure, I think no one will deny that this location is an excellent one so far as its revenues can be affected by local travel and traffic.

The depot or depots for freight to be received at or shipped from St. Louis must, because of the greater cheapness of the ground required, be located on the opposite shore. Nowhere on this side, within a reasonable distance of the business centre of your city, could the requisite quantity of land for a great union freight depot be obtained except at immense cost. Opposite the city, and near the eastern terminus of the Bridge, however, this need can be supplied at a comparatively moderate price. The Bridge and its approaches being less than three-quarters of a mile long, and having its western terminus in the very heart of the business quarter of St. Louis, it follows that, by this location, and the establishment of freight depots near the eastern terminus of the Bridge in Illinois, goods can be carted within more moderate and convenient distances from or to the depots on the other side and the warehouses in St. Louis, than would be possible by any other location.

When the location is considered with reference to expediting and cheapening the transportation of through freights and passengers arriving and departing by any of the ten railroads that are now to be provided with such facilities by this Bridge, it becomes apparent that a location that is not central can only benefit some few of them, at the expense of the others. The roads which are now constructed

from the East all converge to a space not one mile in extent, on the opposite shore, and their termini are all nearly opposite the centre of the city. From the western end of the Bridge, at Washington avenue and Third street, a tunnel 5,000 feet long will extend under Washington avenue and Eleventh street, connecting the railway tracks on the Bridge with the low grounds forming the bed of the old Chouteau pond, on which the Pacific track is laid. The North Missouri, the Southwest Pacific, and the Iron Mountain roads, can all be brought through the valley by which the Pacific road reaches the site of the Chouteau pond, at a moderate cost; and the erection of a union passenger depot near the end of the tunnel will enable all four of the Missouri roads to receive from, and exchange passengers with the roads on the Illinois shore, whose trains can all be run into this depot, where they will receive and deposit their passengers and baggage. Through the tunnel and the Bridge the freight trains from Missouri can be taken to the union freight depot in East St. Louis, and there receive, discharge, or exchange their cargoes. Of course, the establishment of these two union depots for freight and passengers will not prevent the several roads from having such other depots as they may find useful. The union depots will be required chiefly to facilitate the rapid and cheap transfer of freights, passengers and baggage from one road to another.

I am aware that many persons maintain that facilitating the transfer of freights and passengers will cause our people to lose the profit that arises from hauling them from depot to depot, and in entertaining the passengers at our hotels and boarding houses. This policy is so short-sighted as scarcely to need noticing. The great struggle now being made by so many rival lines and cities for the trade of the West, should admonish us that unless we, too, offer inducements on the score of economy, convenience and dispatch, we can scarcely hope to maintain what we now have. Let us secure this trade by expediting it in every way in our power, and by lessening the burdens with which it is now taxed. The marvelous rapidity with which it will then multiply on our hands will give our people greatly increased profit and employment.

In deference to the views of railroad gentlemen of great experience, I caused surveys and examinations to be made to determine the propriety of locating the Bridge at the northern part of the city, opposite the town of Venice.

It was asserted that at this locality the bed rock of the river formed the bottom of the channel, and that the piers could be cheaply and readily erected on it. Borings made by me near the Illinois shore, to ascertain the truth of this assertion, prove the rock to be overlaid with 60 feet of sand. On the Missouri side, examinations made by the Board of Water Commissioners show the rock to be 30 feet below the sand. Borings made by the late Mr. Homer, City Engineer; by

Colonel Bissell, C. E., and by myself, at various places between the one in question and Washington avenue, leave no reason to doubt that the rock there slopes with the same regularity from west to east that we know it does at other localities in this harbor, and is nearly or quite as far below the surface as at Washington avenue.

The river at that point being much wider than at Washington avenue, the erection of a bridge there would involve the necessity of more piers, and a greater length of superstructure. The extensive plateau on this side, scarcely above the city directrix, would require the construction of an expensive approach of from 1,500 to 2,000 feet, according to the grade, while it would not be possible to connect with any Missouri road, except the North Missouri, without the construction of several miles of road, extending through the public streets of North St. Louis, and thence by a circuitous and expensive route back of the city to the Pacific road. From Rocky Branch, in the extreme northern part of St. Louis, to the valley half a mile south of Washington avenue, through which the Pacific road comes in, there extends an almost unbroken ridge or plateau, varying from 75 to 125 feet above the level of the Pacific track at Eleventh street. This ridge would interpose expensive difficulties in connecting the structure with any Missouri road except the North Missouri. In Illinois, only the two roads coming in from the northeast could use the Bridge advantageously when connecting with the North Missouri. A bridge thus located could only be used by the Missouri Pacific, the Southwest Pacific, and Iron Mountain, on this side, by the construction of an expensive piece of road of three or four miles in length; and in connecting those roads with the Ohio and Mississippi, the Vandalia road, the Belleville, and the Cairo roads, on the other side, they would do so at a loss of from three to five miles in distance. Of course, this location is only advocated for a railroad bridge. Local traffic on it, except to a very limited amount, could not be expected.

For railroad purposes, except in the interest of the North Missouri, Alton and Terre Haute, and St. Louis and Chicago railways, the location has nothing whatever to recommend it, while the advantages accruing to those roads from a connection at Venice would not compare with those that will be derived by them from the central location at Washington avenue. By the Venice location, it would be idle to hope for a union depot almost in the very heart of the city, for the convenient transfer of passengers and baggage. By the location at Washington avenue, this is attained without extra cost to the roads in making the connections with each other, and without danger of interruption from over-crowded streets, or risk of injury to persons or property.

As a matter of convenience to the marine interests, the location at Washington avenue must be deemed judicious. It is idle to talk of bridging the river, and planting piers in its channel, without ob-

structing navigation. No matter how wide the spans may be, every pier that is placed in the river is an obstruction, calculated to create danger, and cause anxiety to those who navigate it. By the location at Washington avenue, the wharf is nearly equally divided above and below the Bridge. This will make it unnecessary for the steamers trading on the upper rivers to pass under the structure, whilst those engaged on the Ohio and the lower rivers will seldom be required to pass above it. If the Bridge were located in the upper portion of the city, all of the upper river boats would have to pass and repass it every trip.

From all these facts, I feel confirmed in asserting that at no other location could the Bridge be erected so cheaply, at no other one would its revenue be so great, and at no other point opposite your city would the public at large be so well accommodated.

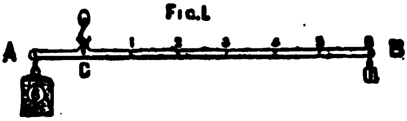
ARCH AND TRUSS BRIDGES.

Because of the frequent assertion that your structure will be needlessly extravagant, I deem it proper to illustrate, in as simple a manner as I possibly can, enough of the general principles involved in the construction of bridges to enable any one to satisfy himself that the plan adopted for the construction of this Bridge, instead of being needlessly expensive, is really the most economical of all known methods. The general principles involved in the construction of an *arch* or a *truss* are not so intricate or difficult but what any one with ordinary intelligence can, with a little explanation, comprehend them sufficiently to judge for himself of the truth of this assertion. I shall do this before proceeding to an explanation of the plan of your proposed Bridge, as the method adopted in it will then be more readily understood and its merits appreciated.

Any one who can be made to understand the principles of the simplest of all the mechanical powers, the *lever*, can readily comprehend the explanation I propose making, and though he may never have reflected upon the subject, a few minutes spent in carefully considering the following illustrations will be sufficient to enable him to understand the economy of the arch, over the truss, for long span bridges.

Suppose the lever A B (Fig. 1) to rest on the fulcrum C, so that the long arm is six times the length of the short one, then it is evident that one ton placed at B will balance six tons at A.

FIG. 1.



If the short arm of the lever be bent down, as in Fig. 2, one ton at B will exert a force equal to six tons at A in the direction of the ar-

row; and it will create a pulling or tensile strain on the hook at the same time equal to six tons. If two such levers be placed together, as in Fig. 3, with one ton weight on each at B (two tons on the two), then the strain of six tons on the hook in Fig. 2 will be transferred to B, where the two ends of the lever will press against, and mutually support, each other. To retain the short ends of the levers at D and E from separating, it will be necessary to tie them together with a cord, D E, capable of sustaining a strain of six tons, that being the strain at A (Fig. 2) in the direction of the arrow. Anything interposed between the levers at B would be subjected to a crushing or compressive force of six tons.

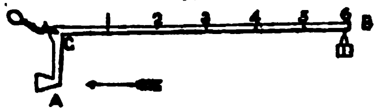


FIG. 2.

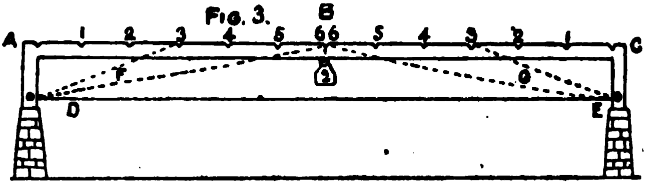


FIG. 3.

The two long arms of the levers (Fig. 3) here represent the upper or compression member of a truss sustaining a crushing force of six tons, while the chord is the tension member, and is resisting, at the same time, a strain of six tons that is endeavoring to tear it asunder. If the upper member fails to resist the crushing force, or the lower one is rent asunder, the truss must fall.

To avoid complicating the explanation, the illustration assumes that the levers are perfectly rigid, and makes no account of their weight. If, instead of placing the two tons at B, Fig. 3, we suppose

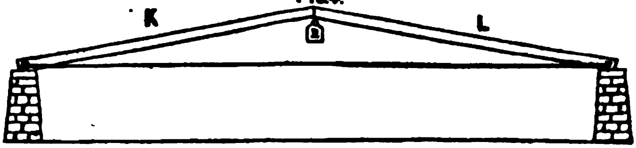


FIG. 4.

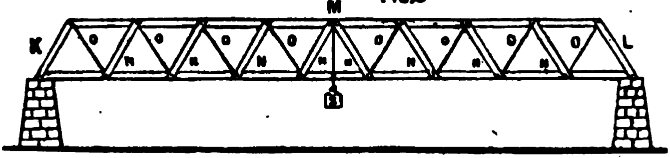
their long arms were each of one ton weight, then the strain would be only half as great; for, if we remove the weight at B (Fig. 1), and suppose the long arm of the lever to weigh just one ton, then this arm will only balance three tons at A, for the centre of gravity of the arm

will be at the point 3 on the lever, and at this point a ton weight will only produce half the strain it would if placed at the end of the lever, the point 3 being only half the distance from the fulcrum that B is.

The strain upon the chord (Fig. 3) comes from the weights at B acting in the direction of the dotted lines, F G; hence, by substituting the straight members, K and L (Fig. 4), for the bent levers, these members will be subjected to the same crushing strain, and, being shorter, will be more economical in material. This simple, triangular truss represents the most economic of all forms of short trusses known.

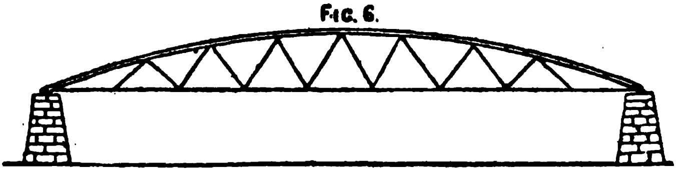
If we desire to extend the span of this truss, the members K and L are liable to bend downwards with their own weight. To obviate this difficulty, many expedients are resorted to; one method is shown in Fig. 5, which is by the introduction of a third member, M (forming

FIG. 5



the top of the truss), and the braces N N, and also the tie-rods, O O. Here K, M and L sustain the entire compressive force exerted by the weight of the whole structure. These members may be made with

FIG. 6.



less material by curving them in the form of an arch, as in Fig. 6. This constitutes the bow-string girder. It will be observed that as the compressive and tensile strains are about equal, the truss requires about the same quantity of material in the lower member for tension that it does in the upper or compression member, when the material is the same in both, while the latter is really the sole supporting member of the structure.

The illustration of the lever shows that the strain on the compression and tension members is increased by diminishing the height or

depth of the truss. For instance: if the short arm of the lever is only one-twelfth of the length of the other arm, instead of one-sixth, as in Fig. 2, the same weight would create twice as much strain at A as before. The truss, in that case, would be twenty-four times its height in length, instead of twelve times, as in the illustration at Fig. 3. Thus, making the height less, requires more material in the upper and lower members, and making it greater, requires more in the braces N N, and in the tension rods O O, as they must then be longer. The proportions that insure the greatest economy are found to be about one-tenth of the length of span for the height, varying, however, in different systems from one-eighth to one-twelfth.

The bow-string girder (Fig. 6) requires theoretically probably as little material in its construction, in proportion to the weight to be sustained, as any form of truss known. If we support the compression member or arch of this truss (Fig. 7) between stone abutments

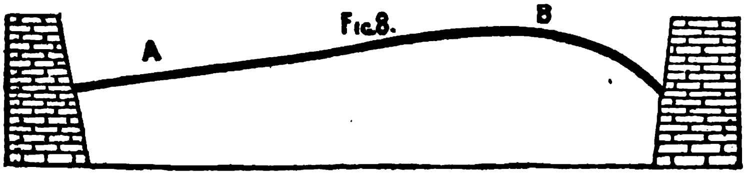
FIG. 7.

strong enough to bear six tons of horizontal thrust, or exactly what its lower member must sustain, we can then dispense with the latter altogether, for it must be evident that its only purpose is to keep the bow or arch from spreading at its ends. If the truss must be supported on piers, it will at once become an interesting question, what will be the difference between the cost of the light piers needed to uphold the truss, and the heavier ones required to sustain the horizontal thrust of the arch. By the horizontal *thrust* of the arch, w mean the strain thrown by it upon the tension member in the truss. Of course, if this member be dispensed with, the abutments must sustain this thrust; and their ability to sustain it is simply a question of weight and arrangement of stone. The force of the thrust is easily known by calculation, and when we know that one cubic yard of stone will require a certain force to move it, we can readily calculate how many cubic yards of it will be required to resist a given force or thrust. As no account of the bond of the cement is taken in the calculation, we will have that much additional safety in the abutment. If the excess of masonry required for abutments be found to cost less than the tension member, then the arch (or the bow without the chord) will be the cheaper structure. It may occur, too, that because of floods, ice and drift, it may be prudent to use heavier piers

than would otherwise sustain the truss. This would be an additional argument favoring the use of the arch.

By referring to Fig. 6 it will be seen that the bracing between the arch and the chord, as well as almost the whole of the chord itself, is suspended from the arch. In a span of 500 feet, these braces at the centre of the arch would be from 50 to 75 feet long, and their weight and that of the chord would be enormous; yet they bear no part of the load, but serve only to preserve the form of the bow. The sole sustaining member of this truss is therefore the compressive member or arch. It must be evident, then, that by sustaining that member between abutments we not only save the cost of the tension member and bracing, but we relieve the arch of this constant and enormous weight also. Now, if this bow-string truss were simply strong enough to bear its own weight before, the same arch supported between abutments, as in Fig. 7, and relieved of this weight, would then sustain an imposed load on the Bridge equally as great as the weight of the tension member and braces taken away. Indeed, if the span of the truss were 500 feet, these needless members would equal the weight of two loaded trains of cars throughout its entire length. It will be asserted that the tension member is all that is saved by using the abutments, because the bracing is needed to preserve the form of the arch also, when but one-half of the span is loaded, whether we use the tension chord or the abutments. This is true, but in the latter case a much smaller quantity of bracing material is needed, as I shall soon prove.

I have purposely taken that form of truss which is of all others the most favorable to those who may be disposed to question the propriety of using the arch in the Bridge at this location, because in no



other form of truss with the distributed load, even in theory, can the braces be omitted. (In the tubular girder, the vertical plates forming the sides of the truss constitute the bracing between the upper and lower members.)

Referring to Fig. 7, if this arch be of equal weight throughout its length, and parabolic in form, with a load equally distributed, it will be self-sustaining, and will require no bracing; but when a moving

load at A (Fig. 8) has covered that end of the arch, it will be straightened, and the unloaded portion at B will be bent upward.

As the strength of the arch is dependent upon its form, it is necessary to adopt such means as will preserve it in shape under all trials to which it may be subjected. The usual method of counteracting the effect of the moving load, is by spandrel bracing (Fig. 9.) Here A B is a member extending over the arch from pier to pier. To this

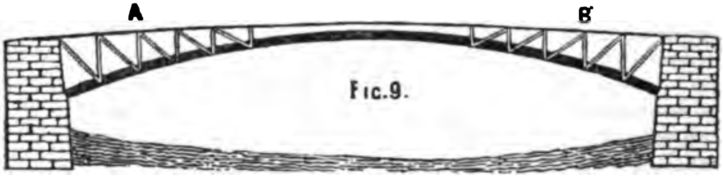


FIG. 9.

member are secured braces and tension rods, extending from it down to the arch, to which they are also secured. The spaces thus occupied by the bracing are called the spandrels of the arch. We here have the member A B extending over the whole length of the span, sustaining no part of the load, but adding so much weight to the arch. Although it is not subjected to so much strain as the chord in the bow-string truss (Fig. 6), and is consequently much lighter, still, it may be dispensed with altogether, if we divide the material in the arch and place one-half of it a few feet below the other, and thus form two arches with about half the original material in each, as in Fig. 10, and brace these two arches or ribs thus made in such manner that they will preserve their form and relative distance from each other,

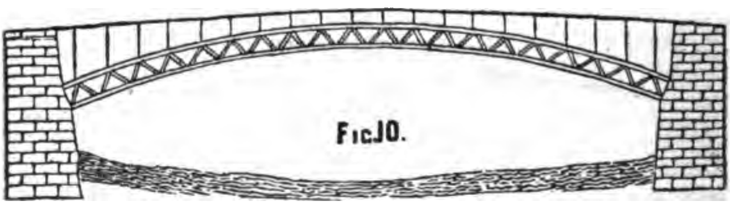


FIG. 10.

under all circumstances. This is what is usually termed the ribbed arch, and is the form adopted for your Bridge. The roadway above it may be of wood, and can be carried by light struts resting on the arch. We require only a little more material in the arch thus formed to carry a given load than is required in the compressive member alone of the bow-string girder, and we only need the two parts of it far enough asunder to insure sufficient stiffness to resist the strains produced by the partial load. In a 515 feet span, if made of cast steel,

eight feet from centre to centre of the ribs is found to be sufficient to sustain the form of the arch when one-half of the span has two tracks covered with locomotives, and the roadway is densely packed with people, the other half of the span being entirely unloaded. The braces for that length of span are only nine feet long, whilst in the bow-string girder of the same span and similar curve of arch, the bracing would be greatly longer, and would weigh four or five times as much. Hence, by using the stone abutments, we save *weight* (and consequently *cost*) in the superstructure, in three ways: firstly, by dispensing with the long, heavy bracing; secondly, by dispensing with the tension member of the truss; and, lastly, by using less material in the arch—for it is plain that, as this member must sustain, in either case, the entire load that crosses the Bridge, it must have more material put in it when it has the heavy bracing and the tension member to support also. In a long span the saving in these three items is really enormous, as will be presently shown. The 515 feet span for this Bridge, with the arch, made of cast steel, weighs about 1,400 tons, exclusive of timber; with the timber, it weighs about 2,000 tons. If the arch were held by a tension member, instead of abutments, that member would weigh about 450 tons, supposing the steel used in it to bear a strain of 20,000 pounds per square inch. But as the arch is only calculated to bear about 3,600 tons, including its own weight, the extra weight of this member would require the arch to be increased in its dimensions by the addition of about 50 tons of steel, making 500 tons in all for one span. At $350 per ton for the steel, this would increase the cost of the span $175,000. The three bow-string girder spans, if made of cast steel, would, therefore, cost over half a million dollars more than the three ribbed arches. They would then weigh 1,500 tons more than the arches, while the saving in the cost of the four piers for their support could not exceed $250,000.

It matters not what truss be used, a proportionate excess of cost over the arch will be found to prevail in every one of them. Where there is no saving in the cost of masonry, or peculiar features of location excluding the *arch*, there can be no substantial argument in favor of the truss for long spans. By the word truss, I include every known method of bridging except the arch. In all of them there must be both a compression and a tension member. In the arch, but one of these two members of the truss is required; the compression member when the upright arch is used, and the tension member when the catenary or suspended arch is adopted. This principle limits the length of the span in trusses by rapidly increasing their cost, so that we will seldom see them used in excess of 350 feet; whereas, the span of the upright or suspended arch may be almost unlimited. If it can be shown that the arch will be as safe and durable, and the entire structure can be made at less cost, and that its

form is suited for the location, then there can be no reason why it should not be adopted where a long span is desirable.

This explanation will enable any one to understand, if he will take the trouble carefully to consider it, why an arch for the superstructure is cheaper than a truss.

CAPACITY OF THE BRIDGE.

On consulting your Board as to the capacity which the Bridge should possess, I found it was unanimously in favor of the erection of one that should be capable of accommodating the local trade and travel now existing, or likely to exist for many years to come, between this city and those immediately opposite, in Illinois, and at the same time serve for crossing all the trains required by the ten railways radiating in every direction from St. Louis. To accomplish this it was deemed necessary to provide a carriageway of sufficient width to admit of four wagons abreast, two footways, each eight feet wide, for pedestrians, and a double railway track for steam trains.

The accommodation of steam railway traffic and ordinary travel on the same structure, and at the same time, is not an untried experiment. It has been done with entire success on the Niagara bridge, on the high level bridge at Newcastle-on-Tyne, and on several structures of minor note in Europe and America.

To provide a single roadway wide enough to accommodate all of these currents on one level, in such manner as to prevent any annoyance from, or interference with each other, would involve the necessity of a much wider superstructure than if the railways were placed above or below the carriage-way. This wide superstructure would require wider piers and abutments, and thus increase the cost of the entire fabric.

The great number of steam trains to be accommodated by the Bridge makes it absolutely necessary that each track shall be at all times open for their transit, and precludes the possibility of having the rails occupy a road-way to be used, even at stated intervals, by ordinary travel, as is done on some railway bridges where the steam trains cross less frequently. In like manner the great tides of local travel that must constantly occupy the carriage-road, throughout the day and part of the night, preclude its being used in common for steam trains. Hence there would be no alternative if they were all on the same level, but to widen the superstructure to accommodate them. In placing the railways alongside of the carriage road, it would be absolutely necessary that the tracks should be separated from the latter by close partition walls or fences, to prevent the frightening of animals on the Bridge. These walls would increase the weight of the structure, expose a much greater surface to be acted upon by winds, and destroy the attractiveness which the Bridge

would possess if it afforded an uninterrupted view of the river and harbor. For these reasons, it was decided not to place the railways on the same level with the carriage road.

The Federal law requiring the lowest part of the Bridge to be fifty feet in the clear, "measured at the centre of the span," above the city directrix (or ordinary high water), and the level of the railways on the Illinois shore being but a few feet above the directrix, it is plain that if the railways of the Bridge were placed above the carriage-ways, it would greatly increase the length of the necessary railway approaches in Illinois. Instead of their being fifty-two feet above the directrix at the centre of the Bridge, they would have to be at least seventy feet, if they were placed over the carriage-way. This would involve difficulties at the western end of the Bridge also, as the grade would be too great to run the trains under Washington avenue. To have these trains leave or enter upon the Bridge through this crowded avenue would not be desirable, even if the citizens of St. Louis would permit it. To substitute horse power for steam in moving the trains through the avenue would cause extra expense, and would not remedy the difficulty, for the street does not possess the capacity to accommodate the railway business as well as the local traffic of the Bridge; and if used for the former, it would be liable to be blocked up at times from the effect of snow storms, accumulation of trade, or other causes, and would so interfere with the business of the city and the convenience of the people as to become an unbearable nuisance. The accommodation of railway traffic by the Bridge, therefore, if located at Washington avenue, involves the necessity of a tunnel under that street, and the railroad grades on both sides of the river fix the position of the railway tracks on the Bridge below the carriage-way.

By this arrangement, it was found that the carriage-way would be on the same level with Washington avenue at each end of the Bridge, and it would thus form a continuation of that avenue eastward from Third street 2,700 feet long, entirely level, except the slight rise that will be given to the Bridge between the two abutments, to obtain the requisite height over the channel at the centre of the middle span.

The width of the structure and the position of the road-ways being thus determined, the next important step was to decide upon the system that should be adopted on which to construct the Bridge.

The determination to accommodate railway and local traffic on the Bridge, involving, as it does, the necessity of an upper and lower roadway, increases the magnitude of the structure to such a degree as to render a drawbridge out of the question, even if it were not an absurdity to think of opening and closing, thirty or forty times a day, a highway that must be as constantly and as densely thronged as any street in the whole city. As a drawbridge at this city has been, I think very wisely, prohibited by law, I only allude to it to record my disapprobation of such a structure, if it were considered desirable to

obtain a repeal of the restriction. The objections to the use of one at this location are so numerous, and I think so well understood, that I will not occupy your time in detailing them.

In deciding upon the method of superstructure to be adopted, so much depends upon the difficulties presented in securing proper foundations that it becomes necessary to explain something of the magnitude and character of those difficulties in the case, to enable you to understand fully the reasons which impelled me to the adoption of the arch in spans of about 500 feet.

ACTION OF UNDER CURRENTS.

Examinations made by myself and other engineers have revealed the fact that the bed-rock of the river, which is limestone, is overlaid with a deposit of sand about fifteen feet deep near this shore, and perhaps one hundred feet at the other; the increase in depth being very regular as we proceed towards the Illinois shore. The borings, as far as made, indicate a regular slope of the rock from this shore, which has been traced as far as the location of the eastern channel pier, where it is about seventy-nine feet below the deposit. Near the Illinois shore, ninety feet of boring has failed to reach the rock. The sandy bed of the river in low water is nearly level.

Soundings made by me prove that this deposit is scoured out to a great depth in time of floods and freshets. Although I have not had any extreme stage of water in which to make my observations, I found that a rise thirteen feet less than high-water mark caused a scour of eighteen feet. The greatest variation in the height of the river known at this place is about forty-one feet. An average depth of about eight feet, with a width of 1,600 feet, represents the volume of the river at extreme low water at the location selected. Extreme high water covers an immense area of bottom lands above and opposite the city, and the construction of numerous railway dikes across these from East St. Louis, reduces the water-way at Washington avenue to about 2,200 feet in width at high-water mark. On this shore and on the other, this water-way is thoroughly revetted below the low-water line with rubble stone and protected by the wharf pavements above that line. The concentration into this narrow channel of the vast volumes that are sometimes poured out of the gigantic net-work of streams above St. Louis, the main artery alone of which is navigable over a thousand leagues above this city, assures me that in time of floods it is not improbable that this deposit is removed to twice or thrice the depth shown by my soundings, and perhaps to the rock itself.

I had occasion to examine the bottom of the Mississippi, below Cairo, during the flood of 1851, and at sixty-five feet below the surface I found the bed of the river, for at least three feet in depth, a moving

mass, and so unstable that, in endeavoring to find footing on it beneath the bell, my feet penetrated through it until I could feel, although standing erect, the sand rushing past my hands, driven by a current apparently as rapid as that at the surface. I could discover the sand in motion at least two feet below the surface of the bottom, and moving with a velocity diminishing in proportion to the depth at which I thrust my hands into it.

It is a fact well known to those who were engaged in navigating the Mississippi twelve years ago, that the cargo and engine of the steamboat America, sunk 100 miles below the mouth of the Ohio, was recovered, after being submerged twenty years, during which time an island was formed over it and a farm established upon it. Cottonwood trees that grew upon the island attained such size that they were cut into cord-wood and supplied as fuel to the passing steamers. Two floods sufficed to remove every vestige of the island, leaving the wreck of the America uncovered by sand and forty feet below low-water mark, where, in 1856, the property was recovered. Pilots are still navigating the river who saw this wreck lying near the Arkansas shore, with her main deck scarcely below low-water mark at the time she was lost. When the wreck was recovered the main channel of the Mississippi was over it, and the hull of the vessel had been cut down by the action of the current at the bottom nearly forty feet below the level at which it first rested; and the shore had receded from it by the abrasion of the stream nearly half a mile.

These remarkable but well-attested facts came under my own observation, and occurred at Plumb Point, 100 miles below Cairo, where the Mississippi is more than one mile wide, and where the lateral action of the current is not confined, as it is here, by stone, and where the depth of the action of the under currents must be much less than at this narrow passage.

Singularly enough, the fact is almost certain that at seasons of *lowest* water, this deposit is also liable to be removed to an extent probably sufficient to lay bare the rock in mid-channel. The current being much less when the water is low, the sand accumulates to its greatest depth. When the river freezes over, which only occurs when it is quite low, a strong crust of ice, from ten to fifteen inches thick, is formed in this narrow gorge, while there are frequently great stretches of the river above unclosed. The floating ice formed in these open spaces is carried down in large masses, which accumulate in this and other narrow passages of the river, and form what are termed ice gorges. These accumulations sometimes extend several miles above the contracted channels of the river and cause the water to rise, or, in river parlance, "back up," ten, and even twenty feet, in some instances, above its former level. The firmly frozen crust serves to hold the masses that are accumulated beneath it, and the great height attained by the "backing up" of the water above the gorge

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increases the currents that are sweeping below the ice to a degree probably greatly exceeding that of the floods, if we may take the water levels above the gorge as an index to the current created by this hydrostatic pressure. These currents, I believe, would prove too great to be resisted by any ordinary rip-rap (or loose stone) usually used to protect foundations not resting on the rock. The ice being lighter than the water, it follows that these currents will be constantly acting beneath the gorged ice, and in direct contact with the sand. As rapidly as the latter is cut away, fresh supplies of ice are driven under, and thus the mass continues to grow in depth, and the current to be directed nearer to the rock. After a few weeks the pressure of the back-water becomes so enormous as to sweep the gorge away, and on such occasions the open space of water below the gorge is at once filled for miles with the submerged ice thus liberated. This ice can readily be distinguished from the crust or surface ice by its scarcely floating, and by the quantities of sand and mud with which it has been saturated during its imprisonment.

On two occasions I undertook to cut a channel in the ice through which to remove from gorges two valuable diving-bell boats to places of safety. The undertaking was only successful in one case. The surface ice being removed from the canal and hauled off on its sides, I found the quantity of submerged ice which continually arose, when that in sight was removed, was so great that the supply seemed inexhaustible. In the case where I was successful, I was able to cut the channel from an open part of the river up to the vessel, and through it the submerged ice was floated out and the channel thus cleared.

In the winter of 1855, the steamer Garden City, of about 800 tons burden, was inclosed in the ice gorge which formed in this harbor. Many of our citizens will remember that a partial movement of the gorge caused her sides to be crushed, in consequence of which the vessel filled with water. She was lying at the upper part of the city in front of a large stone quarry, the debris from which had been for several years thrown into the river by the quarrymen, and had formed a steep, rugged shore of such slope as the broken stone naturally assumed. The water where the vessel sunk was twenty-five feet deep, but she was sustained upon the gorged ice beneath her, so that her deck was scarcely under the surface. She was in this condition when I was called upon to save her. Her hull being about nine feet in depth, it is evident that the ice which sustained her must have been packed to the bottom, and sixteen feet deep. This ice supported her with her engines and boilers and a cabin over them about 150 feet long, until the bank was removed, ways placed on the ice under the steamer, powerful purchases secured ashore, and the vessel hauled broadside in to, and upon the bank in safety, before the gorge gave way. The time occupied in doing this was about ten days, nearly all

which time the steamer was resting on ice that had been driven under the surface by the action of the current.

The establishment of piers in the channel of the river must facilitate the formation of an ice gorge at the Bridge in the winter, and they will certainly tend to its retention until the sand is scoured out about and between them to an unknown depth.

For these reasons I have maintained and urged that there is no safety short of resting the piers for your Bridge firmly upon the rock itself. On no other question involved in its construction does my judgment more fully assure me that I am correct, although the Convention of Engineers assembled here last summer announced in their report that they did not consider it essential to go to the rock with all the channel piers of Mr. Boomer's bridge. The Convention assumed that the greatest possible scour would not exceed thirty feet below low-water mark, (equivalent to the removal of twenty-two feet of deposit. See Report, page 80.) I am supported in my opinion upon this matter by many eminent engineers with whom I have exchanged views upon the subject.

The recent destruction of many of the bridges in British India, by having their foundations undermined by the action of floods upon the sandy bottoms of the streams in that country, furnishes a warning that we should not neglect.

MAGNITUDE AND NUMBER OF FOUNDATIONS.

The necessity for basing the channel foundations upon the rock being considered imperative, the next question was to determine the most judicious number of piers.

By shortening the spans the cost of the superstructure would be lessened and a reduction in the size of the piers be possible. This would, in ordinary cases, result in a proportionate lessening of the cost of the entire structure. The law, however, requires that at least two spans shall each be not less than 350 feet, and the remaining spans 200 feet in the clear. Therefore, the reduction in cost of the structure by lessening the length of spans is limited to a certain extent by this provision. There are reasons, however, involving the safety of the Bridge, which make it necessary to provide, by an increase of masonry in the piers, the ability to resist the extraordinary casualties to which they will be liable at this location. When we take into account the great height required for the piers, from the rock to the lower roadway of the Bridge (145 feet in one and 174 feet in the other), and remember that by the scour of the current they will be, at times, without the supporting pressure of the sand to resist the strains to which they will be subjected, we have an imperative reason for increasing the size of the piers to a degree sufficient to insure their stability, without reference to any other question whatever.

In another part of this report I have explained why an arch is a cheaper method of *superstructure* than a truss; and that the advantage which the truss has to recommend it, is that it creates no thrust, but simply a vertical pressure upon the piers, thus enabling the latter to be built with less material than when the arch is used. But here we have an absolute necessity for using massive piers, and hence are unable to avail ourselves of the chief feature of economy that might otherwise make the truss available, and the smallest spans permitted by the law desirable. If we bear in mind that the bed rock deepens as we approach the Illinois shore, it will be seen that by adopting shorter spans it becomes necessary to erect piers nearer to that shore, and these must be put down through a greater depth of deposit than the two contemplated in the plan. The deepest foundation we have to put down will be seventy-nine feet below the bottom of the stream, and we shall probably have an average depth of twenty feet of water during the season that is occupied in placing it in position, making in all ninety-nine feet below the surface of the river. It is certainly not desirable to undertake a deeper one, except for more potent reasons than I can discover in the premises. Shorter spans would make it absolutely necessary to do this, if the piers were placed on the rock. It has been asserted that the erection of 500 feet spans is more hazardous than 350 feet ones. This is admitted; but with ordinary care and judgment the danger of casualties in the erection of either cannot be great. It is certainly more hazardous to erect a structure at this location whose channel piers are not placed upon the bed rock below the river bottom; and if this be done, and shorter spans adopted, the difficulties attendant upon putting down the foundations must necessarily be increased, not only by increasing their number, but also because of the greater depth required for one or more of them. The hazard avoided in erecting the superstructure would simply be added with interest to that attending the construction of the piers.

The magnitude and height of the piers required is so great, even if the spans were lessened and four arches substituted, and the season favorable for their economic erection is so short, extending only from the middle of August to the middle of December, that it would not be advisable to attempt the erection of more than one of them in one year. Hence, an additional one would delay the completion of the Bridge, and absorb in interest on capital as much as could be saved by shortening the spans. It is possible to use the same false works and machinery for each pier, unless we undertake to put in two of them in one season. This would involve the additional expense of duplicating these works and machinery. But little could be saved in the masonry of the piers by substituting three for the two contemplated, as the three would contain nearly as much as the two. There would be more saved in the abutments, but it would be chiefly in

that class of masonry (the backing) which is least expensive. The cost of putting down the necessary false works, removing the deposit, and erecting the three piers, would be considerably greater than for two.

The masonry of your Bridge being so massive in character, has been contracted for at a price greatly under that paid for other large bridges now being constructed in the West. The reason for this is that the slender piers used in the latter require that every stone in them be cut to an exact size. This is only necessary with the exterior work in yours, and hence it can be and is being executed for about 30 per cent. less than the masonry of those bridges.

The question of relative economy of shorter spans has not been determined by guess work, or decided by judgment alone, but the conclusions arrived at in favor of the spans adopted have been confirmed by careful estimate and calculation to be not only the most judicious, but also the most economical arrangement compatible with the safety of the structure.

It is not considered advisable to place the abutment at the Illinois shore upon the rock. The cost of doing this would be very great, and as the piles upon which the masonry will be erected can be thoroughly protected at the shore from the action of the current, it will not be necessary to do it. The sand on the site of the abutment will be excavated to a point about twenty-five feet below the bottom of the river, and piles will then be driven to the greatest depth possible and sawed off a few feet above the sand. The spaces between the piles will be carefully filled, and the masonry laid upon a timber platform on the bed thus formed. The face of this abutment below water will then be thoroughly revetted with stone.

The rock has been laid bare thirteen feet below low-water mark on the Missouri shore, and the western abutment commenced upon it within the coffer-dam built for the purpose.

METHOD OF SINKING THE PIERS.

A number of designs and estimates were made by me to determine the most practicable, economical and reliable method of constructing the parts of the channel piers below low-water mark. These designs and estimates included the use of cast iron cylinders, of diameters varying in the different plans from three to fifteen feet, which were to be sunk to the rock and filled with concrete. The danger of scour, and the difficulty of binding these cylinders together beneath the surface of the sand, so as to insure stability under the strains produced by the thrust of the arches, induced me to increase their diameters in subsequent designs, until they became so great that wrought iron was substituted, and finally two cylinders, each of a diameter equal to the width of the pier, were tried with smaller ones about them,

to complete the entire dimensions of the foundation. The same difficulty of binding these together in a manner to insure safety to the superincumbent masonry, in the event of deep scour, as well as to give promise of any great durability, still remained.

Cast-iron cylinders may be used with great advantage in forming subaqueous foundations in situations where there is no scour; but the dangers to be guarded against in this location would render them, I think, less reliable and more expensive than other methods.

My experience of the effects of fresh water upon wrought and cast-iron, submerged for many years in the Mississippi, assures me that the latter can be relied upon as almost indestructible, but that wrought-iron will oxidize or rust out so rapidly that in twenty years the strength of a bolt an inch and a half in diameter would probably be reduced one-half. To bind these cylinders together, beneath the sand, would greatly increase the cost of adopting them, and to use wrought-iron to secure them above the sand would fail to insure durability. To undertake to do it with cast-iron would be more expensive, and the slightest unequal settlement of the different ones composing the mass would be likely to fracture a material so brittle. To sink these cylinders, either by the pneumatic process or by any of the methods known, to the requisite depth, would be exceedingly expensive. The great quantity of iron required in them, and the fact that they must be filled with masonry, would render a foundation of the necessary dimensions, if composed of them, much more expensive than if made of stone alone.

Having arrived at this point in the solution of the most important problem connected with the design and erection of your Bridge, I determined to construct the base of the pier entirely of solid masonry, within a water-tight floating coffer-dam, whose sides should be extended above water, from time to time, as it sunk deeper and deeper, with its increasing burden of stone and cement.

Piers of smaller dimensions have been constructed in a similar manner, and placed upon foundations favorable to their permanent reception. When sand or mud has been interposed, and its removal rendered necessary, the sides of the floating vessel have been extended downward below its bottom, to form a chamber or kind of diving-bell beneath the masonry. Through the masonry, tubes were provided by which workmen and materials could descend into the chamber, and through these tubes air was forced to expel the water from the chamber, and enable the workmen to remove the sand or mud beneath the pier. These tubes required to have two or more air-locks or valves in them, that were closed behind the workmen or materials in their passage, to prevent the escapement of the compressed air in the chamber. This of course retarded the rapid progress of the work. To facilitate the excavation of the deposit an extra tube was introduced in the middle of the pier and extended to the level of the bot-

tom of the air chamber. The water stood within this tube at the level of the surface of the river, and through it an endless chain, carrying scoops or excavators, was made to rotate around a pulley at the bottom of the tube, and another at the top. In this way the sand was rapidly excavated without permitting the escapement of air from the chamber, and without passing the deposit up through the air-locks. The workmen in the chamber were enabled to shovel it to the bottom of the tube, where it was taken by the excavator, and discharged in vessels above.

The gradual descent of the pier was managed by screws, supported upon false works, erected around and over the site of the pier. As the sand was removed below, the pier was allowed to settle by slacking the screws, as it was only partially water-borne. When it had passed through a considerable depth of sand, the friction of the latter, upon the sides of the pier, held it to such a degree as to take all the strain off the screws, and when it moved downward it was sometimes so suddenly that the supports were strained severely.

The shortness of the season in which each one of the piers for this Bridge must be put in position, because of the floods of Summer and the ice of Winter, and the great amount of deposit to be removed, renders the pneumatic process just described too slow for this case, as well as too expensive. For the safety of the workmen beneath the pier, it is absolutely necessary to regulate its descent by screws or similar means, and to do this with piers of such magnitude would not be advisable.

The removal of the sand will be accomplished by sinking an elliptical-shaped caisson or curb of plate-iron through the deposit to the rock. This caisson will be open at top and bottom, and will be strongly braced on the inside with heavy angle irons placed horizontally around it. It will be larger at bottom than top, to facilitate its passage through the sand and relieve it of the friction. The caisson will be suspended by false works erected around the site of the pier, and will be regulated in its descent by screws supported on the false works. As it is lowered into the sand, that which is inclosed by it will be excavated by steam machinery, until the caisson is finally sunk to the rock. It is not intended at any time to remove the water within the caisson, but only the sand it incloses; the object of the caisson being only to exclude the sand outside of it until that which it incloses has been removed, the rock leveled off with concrete, the floating coffer-dam placed in position within the caisson, and the pier so far built up in the latter as to sink it down to the concrete bed prepared for it.

The bottom of the coffer-dam will be formed of squared timbers, thoroughly caulked, and will be about two feet in thickness. Its sides will also be of timber, and so constructed as to admit of being disengaged from the bottom when the latter has reached the bed formed

to receive it. The interior of the coffer-dam will be larger than the pier, and the latter will be constructed with certain cavities in it to be filled with masonry after the pier reaches the bottom, so that the weight of the pier will bear such proportion to the displacement of water as to insure the top of the masonry being kept but little below the surface of the river while the pier is being built within it. This will enable the sides of the vessel to be thoroughly braced against the pier so as to resist the pressure of the water.

It is known that timber is indestructible when completely submerged in fresh water. Piles placed in the Rhine by the Romans, nearly 2,000 years ago, have been found to be entirely sound when removed within the present century. There are many other similar instances on record establishing the fact of its durability, whilst the soundness of the timber found in the bogs of Ireland and elsewhere indicates that it is unlimited by time.

When the bed rock has been prepared to receive the pier, the coffer-dam will be floated within the caisson, and will be guided by the latter as it descends with its load. It will be understood that the pier is completely water-borne by the coffer-dam until the quantity of masonry in it has become so great as to cause the dam to touch the bed on which its bottom, with the pier, is to rest permanently. When the pier has been completed above water, the dam is permitted to fill, and its sides will then be disengaged from the bottom and removed, to be used in putting down the next pier. The caisson for the smaller pier can be withdrawn and used for the other one; and the larger one may possibly be saved also.

As before stated, the floating coffer-dam is not an untried experiment, but has been frequently used to place piers in position where the bed-rock or other substratum was favorable for their reception. The caisson has also been frequently used to exclude the sand or mud, and enable that within it to be removed sufficiently to facilitate the driving of piles to a greater depth and in firmer soil than would be otherwise practicable.

The estimates made for the cost of this work prove that it will be much less expensive than any other method yet devised; while the superiority of the foundations thus made will be beyond all question.

PLAN OF STRUCTURE.

The Bridge will have three spans, each formed with four ribbed arches made of cast steel. The centre span will be 515 feet and the side ones 497 feet each, in the clear. The rise of the centre one will be one-tenth of the span; that of the side ones forty-seven feet ten inches each.

The four arches forming each of these spans will each consist of an upper and lower curved member or rib, extending from pier to pier.

Each of these members will consist of two parallel steel tubes, nine inches in exterior diameter, placed side by side. The upper and lower members will be eight feet apart, measured from the centre of the upper to the centre of the lower tubes. At regular intervals of about nine feet, these members will be braced from each other by a vertical system of cast-steel bracing on each side of them. These braces will be secured at each end to cast-steel plates, formed something like the voussoirs of a stone arch, and against which the tubes will be abutted and secured every nine feet throughout the arches. A horizontal system of bracing will extend from pier to pier between the four upper curved members, and a similar system between the four lower ones, for the purpose of securing the four arches in their relative distances from each other, and to sustain them against lateral pressure.

The two centre arches of each span will be 13 feet 9½ inches apart from centre to centre, and will have, in addition to the upper and lower horizontal bracing just described, a system of diagonal bracing, securing the upper member of one arch to the lower one of the other arch, and the two other members in like manner. The outside arches are each 15 feet 1¾ inches from the middle ones, and are joined to the latter by three systems of bracing similar to those described as between the two centre arches. These systems, however, on the outside of the middle arches, extend only from the piers to the under side of the railways, the latter being carried between the two outer and the two inner arches near their crowns; the outside arches being supported in this interval against lateral movement by rigid connections from both the upper and lower roadways.

The roadways are formed by transverse iron beams, twelve inches in depth, supported by iron struts of cruciform section resting on the arches at the points where the vertical bracing of the latter is secured. That portion of the railways which passes below the crown of the arches is suspended from them. Between the iron beams forming the roadways, four parallel systems of longitudinal wooden members are introduced, extending from pier to pier and serving to maintain the iron beams in position. These wooden members are each about nine feet long, and their ends rest upon the flanches of the beams, and are there secured from moving. On these, the wooden beams for the carriage-way rest in one roadway, and the cross-ties for the railways in the other. From the opposite ends of the iron beams a double system of diagonal horizontal iron bracing serves to bind the whole together, and gives additional support against wind pressure.

The upper roadway is thirty-four feet wide between the footwalks. The latter are each eight feet wide, making the Bridge fifty feet wide between the railings.

The railway passages below the carriage-way will each be 13 feet

6 inches in the clear and 18 feet high, and will extend through arched openings of equal size in the abutments and piers.

The railways will be carried over the wharfs on each side of the river on five stone arches, each twenty-six feet wide, and will be inclosed throughout this distance by a cut stone arcade of twenty arches supporting the upper roadway. After passing over those stone arches, the railways will be carried through the blocks between the wharf and Third street on brick arches into the tunnel at Third street and Washington avenue. Over the intervening streets they will be carried on wrought-iron trusses.

On the Illinois shore the railways will curve off to the north and south immediately after crossing the last one of the stone arches, and with a descending grade of one foot in one hundred, extending about 3,000 feet, and supported on trestle work part of the way, they will reach the grade of the railways in East St. Louis.

The carriage road will begin to descend with a grade of five feet in one hundred, at the eastern end of the Bridge, immediately after the railway tracks curve away from the latter, and will conform at Third street, in East St. Louis, to the grade of that street. On the Missouri side the carriage-way will be continued over the railway tracks from the Bridge to Third street on a level grade.

MASONRY.

The greater part of the stone for the Bridge will be taken from the Grafton quarries, on the Mississippi, in Illinois, about forty miles above St. Louis. This stone is a magnesian limestone, of fine, firm texture, yellowish in color, and is found in regular strata, varying from one to three feet in thickness. From severe chemical tests, and the proofs of its durability given in many of the large buildings in this city constructed with it, it is believed to be well suited for the intended purpose. It will not, however, be used on the exterior of the work above water. From two feet below low-water mark to two feet above high-water mark, the exterior of the piers, including those on the wharfs as well as the abutments, will be of the best quality of granite. This will be laid in courses not less than thirty inches thick, with an arris cut around each block to indicate the joints of the work, while the remainder of the block will retain the quarry or rough face upon it. Above the granite, the exterior will be entirely of cut sandstone. A granite course, eight feet in thickness, will be laid through the channel piers, and in the abutments, to receive the skew-backs or heavy cast-iron plates, against which the ends of the arches will rest.

STRENGTH OF THE BRIDGE.

The arches have been designed with sufficient strength to sustain the greatest number of people that can stand together upon the carriage-way and foot-paths from end to end of the Bridge, and at the same time have each railway track below covered from end to end with locomotives. With this enormous load the strength of the arches will be taxed to the extent of less than one-sixth of the ultimate strength of the steel of which they will be constructed. The piers and abutments have been designed with a view to sustain either span when thus loaded, even if the others were entirely unloaded, and to sustain either span entire if from any cause the adjoining ones should be destroyed. The arches have also been designed to resist the effects of any portion of the span being loaded, as above stated, with any other portion of the same span entirely unloaded.

It will be seen, therefore, that the Bridge has been designed to sustain a greater load than will ever be placed upon it. No occasion can possibly occur requiring it to be densely packed with human beings on the upper roadway, and at the same time have its railways covered with locomotives below. Yet the ultimate strength of the materials of which it will be composed is such that the three arches are capable of sustaining 28,972 tons before they would give way under it.

The superabundant strength of the piers to resist the effects of ice, and the ability of the superstructure to withstand the most violent tornadoes, are clearly demonstrated in the appendix to this report.

It has been asserted by some of your opposers that the pressure of such long arches upon the abutments would be so great that the stone would crush under the effect of it. The ridiculous absurdity of this statement is exposed by the fact, that one block of ordinary limestone, six feet square, requires a greater load to crush it than the heaviest burden that can possibly be imposed upon all three of the arches of your Bridge with the entire weight of the three spans themselves added to it. The weight of the three spans, and the maximum load they are designed to bear, is seven and two-tenths tons per lineal foot, or 10,865 tons. The six feet cube of limestone will require 5,000 pounds per square inch, or 12,960 tons, to crush it. I have already stated that the thrust of the piers would be taken upon granite courses, eight feet thick. Granite being more than twice as strong as limestone, the absurdity of this notion is still more apparent. As the thrust of each end of each arch will be received on a surface of granite equal to twenty-four square feet, and as each span has four arches, it follows that the thrust of the three spans is taken on a surface of 576 square feet of granite. This would require, at 10,000 pounds to the square inch, 414,720 tons to crush it,—proving that of all the ridiculous assertions advanced, this is the most ex-

travagant. It could only be excelled by the fear that the tremendous thrust of these 500-feet arches will prove so great as to force the banks of the stream asunder, and let the fabric into the abyss through which the mighty river would then escape.

EFFECTS OF TEMPERATURE.

By making the longitudinal members of the roadways of wood we avoid the expansion and contraction of those long level platforms between the piers, and leave them to be affected only by the action on the arches.

The longest of the arches will rise at the centre a little less than eight inches by the expansion of the steel when under the greatest extreme of heat, and with the most intense cold it will fall as much below the point at which it will be maintained under a medium temperature. This supposes a range of temperature from 20 degrees below zero to 140 degrees above (Fahr.). In the appendix it will be seen that in determining the size of the several parts of the arch, we have duly considered the strains resulting from this change of form. The severest strain produced by temperature occurs at the abutments, and does not amount to over four tons per square inch.

The effect on the roadways is simply to raise and lower them at the centre of the arches so imperceptibly that the eye could not detect it. The rise and fall of the roadways of the Niagara bridge is stated by Mr. Roebling to be 2¼ feet at the centre of the span, under a change of 100 degrees of temperature. That is, the roadways are 2 feet 3 inches higher at zero than when the thermometer marks 100 degrees. No inconvenience has been found to arise from this change of form in that bridge, and none can be apprehended from it in yours, where it is so much less.

There is no truss combined with the arch in the method adopted. The roadways being simply carried on vertical supports by the arches, form no part of a truss system. The arches are the sole supporting members of the structure, and by the vertical bracing between their upper and lower parts, are made amply rigid to sustain their burdens without the use of a truss in combination with them.

I am thus particular in stating this fact, as one of the misapprehensions existing in regard to the plan adopted by you is, that it is a combination of the arch and truss. The well-known difficulties caused by the unequal expansion and contraction of each, when the two systems are combined in a metal structure of long span, would naturally create a want of confidence in your plans, if this impression were permitted to prevail.

TUNNEL.

The centre line of the Bridge strikes the eastern side of Third street, fifty-three feet north of the northeastern corner of Washington avenue and Third street. At this point the tunnel, which at present has been designed for the accommodation of a single railroad track only, begins. It follows Washington avenue to Ninth street, and by a curve extending through blocks 172, 281, and 280, reaches Eleventh street. It is carried under Eleventh street to Chestnut, when the offset at Market street necessitates another slight curve. After reaching Eleventh street, beyond Market street, the tunnel is carried under Eleventh street to its termination, a few feet beyond Clark avenue. Its entire length will be 4,800 feet. The railroad thence is carried to its junction with the Pacific, the Iron Mountain, and the Southwest Pacific Railroads through an open cut.

The width of the tunnel is fifteen feet; its height from top of rail to crown of arch is seventeen feet. The grade in the tunnel is fifty-five feet per mile for a distance of 1,300 feet, while the remainder has grades varying from ten to twenty-two feet per mile.

The depth of the exterior crown of the arch, below the grade of the street, varies from two to ten feet. The sewers intercepted by the tunnel are not very large (2½ by 3½ feet on Washington avenue, and 3½ by 4½ feet on Seventh street). New sewers carried alongside the tunnel will provide for the drainage of those intercepted.

Water and gas-pipes will be carried through the crown of the tunnel.

The apprehension felt by some persons that in the construction of this tunnel rock and quicksand would form a source of expense and danger has been set at rest, since borings made under my directions at points about 300 feet apart, throughout the whole length of its proposed centre line, have shown that the only material to be removed is blue and yellow clay.

The tunnel is to be built in sections, and by open cut, and the right for its construction has been granted by the City Council.

WORK DONE.

Under this head I have to report, among other items, the construction of the coffer dam for the western abutment, the excavation of the material inside of the dam to the solid rock, thirteen feet below low water of December, 1863; and the laying of 1,040 cubic yards of the masonry of this abutment. The work on the abutment was stopped on account of high water, after being carried up to an average height of twelve feet, about the 15th of March, and the river has not yet receded enough to allow of a resumption of the work.

Great difficulties were encountered in the construction and maintenance of the coffer dam, by the large number of wrecks of steamers and barges found in that location, which formed an almost impenetrable mass of timber and iron. Parts of three steamboat wrecks, and four barges imbedded in about twelve feet of debris, were encountered and removed within the dam. The work now, however, is beyond any danger, and may be resumed and carried out without interruption as soon as the river recedes a few feet more.

The large frame-work and the machinery for laying the stone, designed to expedite the construction of the channel piers, has been completed and erected over the western abutment, to have the machinery fairly tested and its manipulation fully understood before using it on the piers, where so much depends on the celerity of operations. The machinery is driven by one engine, and is capable of placing 500 tons of stone in position in ten hours. Its performance gives entire satisfaction.

The work on the western abutment was carried on under the superintendence of Mr. Benj. R. Singleton, C. E., who deserves great credit for the zealous performance of the duties intrusted to him.

Since stopping the work on the abutment, the foundations for two of the piers of the arches which carry the roadway across the levee, amounting to 433 cubic yards of masonry, were constructed. There is also on hand a large quantity of cut and undressed stone and cement ready for a resumption of the work.

Under this head should also be mentioned the large amount of office work performed in the calculations and plans for the Bridge. The whole project in all its details has been thoroughly studied, and but little more remains to be done in that line.

CONVENTION OF ENGINEERS.

The organization of two companies about the same time for the purpose of bridging the river at St. Louis, and the rivalry existing between them for nearly twelve months prior to their consolidation under the present organization, was the cause of many difficulties thrown in the way of the construction of your Bridge. One of these companies, generally known as the Boomer Company, called together a Convention of Engineers last August, to consider the question of bridging the Mississippi River at this point. Although composed in part of many distinguished and able engineers, it was known to have been held solely in the interest of that Company. The plans designed for that Company by Mr. S. S. Post, C. E., were laid before it and approved by the Convention. The plans designed for your Bridge, and adopted by you, were not solicited by the Convention for its examination, and at no time, were those plans under consideration

by it. At no time did the Convention take up the subject of bridging the river by *arches*, but simply by *trusses*, and it therefore very properly recommended that no spans exceeding 350 feet in the clear should be adopted.

Notwithstanding all these facts, it was industriously reported by your opponents that the plans adopted for your Bridge had been condemned by that Convention as unsafe, enormously extravagant, and utterly impracticable; and that it had also condemned the location of it as very injudicious. It is because these statements are even yet repeated by parties interested in defeating the erection of the Bridge, and because they are credited by many persons really anxious for its completion, that I call your attention to them, and pronounce them one and all utterly untrue. One effect of these misrepresentations has been to create a belief in the minds of many, that the plans adopted by you will involve a much greater outlay than is really necessary. This impression has been strengthened, no doubt, by the fact that those plans represent piers and abutments much more massive, and a superstructure far more graceful and elegant, than any form of truss bridge yet constructed. Yet one of the most beautiful and graceful structures in this or any other country, with its massive masonry and enormous span, is one of the cheapest ever erected. I refer to the suspended arch bridge of Roebling at Niagara.

We are too prone to associate our contemplation of the beautiful in architecture and engineering with an idea of costliness, which is not always just. It is easy to prove, beyond the possibility of a question, that in no other form could the material in those members of your Bridge which impart to it the chief feature of its gracefulness, be used with such economy.

It rarely occurs that any great enterprise is undertaken and completed without some opposition, no matter how praiseworthy the purpose, or how many millions will be benefited by the work. If the private interests of some one or more individuals are affected by it, opposers, both open and secret, will be on the alert to assail it, and delay or defeat its consummation. It would be strange, indeed, if your undertaking met with nothing but encouragement, and proved an exception to a rule that is, unfortunately, almost invariable. From its inception, you were opposed by a rival Bridge Company, whose antagonism was stimulated and encouraged by the active or passive co-operation of members of two wealthy monopolies (the Ferry and Transfer Companies), and by others, actuated by motives best known to themselves.

The consolidation of the two Bridge Companies has removed the rivalry between them, and every legal doubt as to your chartered privileges also; but the opposing influences of the Ferry and Transfer Companies remain. It would have been wonderful if the plans of your Bridge should have escaped, not only severe criticism, but un-

just misrepresentation also, in a controversy that has prominently occupied the attention of the public for several months past, and elicited great warmth of feeling. In this controversy the safety of the Bridge has occasioned much discussion, and the most ridiculous assertions on this point were again and again repeated. Originating with those who have opposed the erection of the Bridge, these objections have been adopted, in some instances, by men really anxious for your success, but who have not had the time, or felt sufficient personal interest in the matter to investigate it for themselves. Others, again, occupying the position of wealthy citizens, have perhaps felt the necessity of some apology for not aiding an enterprise so commendable, and have willingly adopted these misrepresentations to excuse their own indifference. Instead of generously abstaining from placing obstacles in the path of an enterprise that should command the best wishes of every one, they have in this way aided its most determined opposers.

The effort to create a want of confidence in the safety of your Bridge was supported, to a certain extent, by the fact that this Convention declared in its report that there was no engineering precedent for a span of five hundred feet, and also by stating that "there has been no bridge of the character of that which (in our judgment) is required at this place yet constructed, to furnish us with any reliable and certain data on the serious questions of materials and workmanship in spans of such great length."

By reference to a copy of the official publication, in my office, made by the Dutch Government in January, 1866, of the details and plans of the Kuilinburg bridge over the Leck, an arm of the Rhine in Holland, you will see that its greatest opening is spanned by a truss of 157 meters, or 515 feet in length, constructed on the method used in the bridge at Hartford, Connecticut. This bridge has a double track railway through it, and this truss weighs nearly 2,400 tons, and is partly of steel.

In 1801 the great Scotch engineer, Thomas Telford, proposed to replace the old London Bridge with one of cast iron, having a single arch of *six hundred feet* span. His suspension bridge over the Menai Straits is one of the most substantial structures of the kind in the world, and spans 570 feet. A cast iron arch bridge of a single span of 500 feet was proposed by him in preference to the suspension one, but was rejected by the government, because the arch gave less room on each side of the channel for sailing vessels.

For forty years this remarkable man continued to enrich Scotland and England with some of the most stupendous and successful triumphs of engineering skill to be found in Great Britain. The erection of more than 1,200 bridges by him, many of them of cast iron, made his experience in bridge construction superior to that of any man of

his period. Many of those erected by him are among the largest and most substantial structures in that country.

A select committee was appointed by Parliament to examine his plans for the 600 feet arch, and the opinions of the most eminent, practical and scientific men of the British Empire were taken before it on the subject, among whom were James Watt, John Rennie, Professors Robinson and Playfair of Edidburgh, and Hutton of Woolwich. The plans were approved and adopted, and the work upon this stupendous arch was actually begun.

Although this great work was ultimately abandoned, it was from no want of confidence in the plan, but because (according to Stephenson) the height of the arch (sixty-five feet) involved the necessity of raising the streets leading to it, by which too much valuable property would have been depreciated. In a private letter to a friend, Telford informs him that his plans were adopted for this bridge, and says: "If they will only provide the means, and give me elbow room, I see my way as clear as mending the auld brig at the burn."

Surely, the recorded judgment of such a man as Telford, when sustained by the most eminent men of his day, asserting the practicability of a *cast iron* arch of 600 feet span in 1801, furnishes some "engineering precedent" to justify a span of 100 feet less in 1867.

When we take into account that the limit of the elastic strength of cast iron in compression is only about 8,000 pounds to the square inch, and that in cast steel it is at least seven or eight times greater, and consider the advance that has been made in the knowledge of bridge building since the days of Telford, it is safe to assert that the project of throwing a single arch of cast steel, *two thousand feet* in length, over the Mississippi, is less bold in design, and fully as practicable, as his cast iron arch of 600 feet span. Engineering precedents have nothing to do with the question of length of span in a bridge. It is a money question altogether. The problem to be solved is simply, what length of span will pay best? This being decided, and profit enough assured to justify the outlay, engineering skill and knowledge will be found fully equal to its accomplishment, no matter what may be the length required. That one made of a material eight times as strong as cast iron is unsafe or impracticable 500 feet long, is almost too ridiculous to be noticed, in a country where the assertion is rebuked by Wernwag's *wooden* arch of 340 feet, which spanned the Schuylkill at Philadelphia.

It must be remembered that the report of the Convention has the names of several able engineers appended to it who were not present at its meetings; that those who were present considered no method of construction except trusses; that its deliberations for the solution of the grave questions involved in bridging this river occupied scarcely ten days; and that it was convened almost solely in the interest of Mr. Boomer, who then controlled one of the charters of your consoli-

dated company, and the patent for the truss bridge he intended building. When these facts are considered in connection with each other, it will be understood why the plans for your Bridge were not solicited for comparison with Mr. Post's patent truss; and when you take the statement of Mr. Post himself, as chairman of the committee on superstructure, that to span a clear opening of 500 feet with his truss would cost as much as to span two openings of 350 feet each, and one and a half of 250 feet each, in addition; or that the superstructure of the Bridge, if built on his plan, would cost $750,000 more with one 500 foot span than if two of 350 feet were used, you will understand fully why the preference was given (on the score of economy) to spans of 350 feet.

An investigation by the Convention of the plans adopted by you would have revealed the fact that the superstructure of your Bridge, possessing greater strength than the one it indorses, and with its great openings, could be erected for about $400,000 less than the truss bridge approved by them, with its greatest spans of but 350 feet; and no part of this saving is absorbed by cost of foundations, as those approved by it, on account of the great quantity of iron required, are more expensive also than yours. The proof of these facts will be found in another part of this report, and they are set forth in a manner that admits of no refutation.

It is, however, not so easy to understand why a body so intelligent as this Convention should forget the authority of Telford and his eminent cotemporaries, and the 500 feet truss bridge over the Leck at Kuilinburg, in Holland, and be led into the error of asserting that there was no "engineering precedent" for a span of 500 feet. If it were expected to span this river with an exact copy of some bridge now standing elsewhere, the necessary data could be obtained and applied without convoking so much ability. Any respectable bridge building firm in this country has, no doubt, sufficient engineering talent constantly in its service for such an emergency, and could have had the requisite plans copied and the structure erected, without calling a Convention of such distingushed gentlemen to deliberate upon them. Where *no* "engineering precedent" exists, however, and where data "on the serious questions of materials and workmanship in spans of such great length" *are not* supplied by structures of equal magnitude, there *is* a necessity for bringing to the consideration of the subject the profoundest thought, based upon such a thorough acquaintance with the strength of materials as experience and experiment alone can furnish, together with a knowledge, obtained by careful study and observation, of the laws which guide us in the combination of these materials.

For increasing the dimensions of a truss beyond any now existing, a knowledge of the strength of materials, and the laws that govern their application, was sufficient to enable the convention to deduce

with entire safety, such data from the experience furnished by the 450 foot truss of Brunel, over the Tamar, the 397 feet trusses of the Dirshau Bridge, over the Weichsel, and a dozen others of lesser span, if the Kuilinburg truss were not in existence.

The wording of the report, inconsiderately, and I believe quite unjustly to the members of the Convention, makes that body seem to condemn the adoption, not simply of a *truss* of 500 feet, but a *span* of that length, whereas it really investigated no other methods of construction to determine their relative economy with the truss. It simply compared the 500 and the 350 feet trusses with each other; and instead of being content to condemn the use of the long one on the score of economy alone, which would certainly have been sufficient, it thoughtlessly gives a reason for not using a 500 feet span that is not only unsupported by truth, but which is also a discreditable one to a profession whose greatest merit lies in its ability to overcome difficulties by the application of physical laws, *without* the aid of precedents. By this negligent (or adroit) wording of the report, the professional reputation of the members is made to injure a kindred enterprise of whose existence they were not ignorant, by making each one of them appear to condemn the plans of a rival structure they had never seen. A thing which no one of them would do deliberately, if he valued his own reputation.

The biographer of Telford relates that a scheme for a broad ship-canal was started to connect the Mersey, opposite Liverpool, with the estuary of the Dee, the object being to enable shipping to avoid the shoals and sand banks that obstruct the entrance to the Mersey. Telford entered on the project with great zeal, and his name was widely quoted in connection with it. It appeared, however, that one of its projectors, who had secured the right of pre-emption of the land on which the only possible entrance to the canal could be formed, suddenly sold out for a large sum to the corporation of Liverpool, who were opposed to the plan. His biographer says that "Telford, disgusted at being made the instrument of an apparent fraud upon the public, destroyed all the documents relating to the scheme, and never spoke of it afterward, except in terms of extreme indignation."

Considering that the Convention was assembled solely in the interest of a rival company, and after the fact of your adopting 500 feet spans had been published, the inference drawn from this part of the report is quite conclusive that the eminent reputation and distinguished standing of its members, have been used for a purpose quite similar to that related of Telford; and knowing that the same keen regard for rectitude displayed by that engineer, is shared in by almost every member of a profession based on laws incapable of deception, and the daily application of which, in the routine of their duties, naturally inculcates a love of all that is truthful and correct; I feel

assured that they have cause to feel, and doubtless do feel, equally indignant with Telford.

If there were *no* engineering precedent for 500 feet spans, can it be possible that our knowledge of the science of engineering is so limited as not to teach us whether such plans are safe and practicable? Must we admit that because a thing never has been done, it never can be, when our knowledge and judgment assure us that it is entirely practicable? This shallow reasoning would have defeated the laying of the Atlantic Cable; the spanning of the Menai Straits; the conversion of Harlem Lake into a garden; and left the terrors of the Eddystone without their warning light. The Rhine and the sea would still be alternately claiming dominion over one-half of the territory of a powerful kingdom, if this miserable argument had been suffered to prevail against men who knew, without "an engineering precedent," that the river could be controlled, and a curb put upon the ocean itself.

COMPARISON OF COST.

By the consolidation of the two companies, you have been placed in possession of the estimates for the Bridge designed for Mr. Boomer, and approved by the Convention of Engineers. I propose to compare those estimates with the estimated cost of your Bridge, taking the same prices in each case for the same materials, as far as practicable.

Comparison of the Cost of Construction of a Truss of 500 feet span, with that of a Ribbed Arch of the same span (for equal loads).

The cost of a 500 feet truss is not directly stated in the proceedings and report of the Board of Civil Engineers, but on page 48 of that report we are informed that it was proved in joint committee that "the cost of a span of 520 feet (or 500 feet in the clear) will be more than twice as great per foot of Bridge, as a span of 368 feet," and being in possession of Mr. Post's estimate of cost for a truss of 364 feet span, we can easily deduce the cost of a 500 feet span.

The following is a copy of Mr. Post's estimate:

COST OF ONE SPAN OF 364 FEET—(FOUR TRUSSES.)

Cast Iron	1,732,992	lbs. @	7	cents per lb	$121,309 44
Wrought Iron	1,679,918	"	12	"	201,590 16
Rolled Iron	240,755	"	9	"	21,667 95
Railing for Sidewalks	56,056	"	15	"	8,408 40
Spikes, Bolts, etc	19,656	"	6	"	1,179 36
Trams	65,022		10	cents	6,502 20
Pine Timber	163,200	feet,	8	"	13,056 00
" for protection	14,560	"	4	"	582 40
Oak Timber	34,000	"	10	"	3,400 00

Scaffolding and Raising	36,800 00
Painting	8,000 00
Patent Fees	6,956 04
Testing and Engineering	42,945 19
Contingencies	118,099 28
Total	$590,496 42

Or, $1,622 per lineal foot.

The estimate for the whole superstructure, of which the above is a part, amounts to $3,233,627.82. As the total cost of superstructure, given in page 84 of the proceedings and report of the Board of Civil Engineers, including the cost of 6,000 feet of railway, amounts to $3,638,920, or nearly $400,000 more, it is evident the above cost of the span is not overstated, and it must be plain that if any error is committed in this comparison, it is in favor of the truss bridge.

The cost per lineal foot of bridge of a truss of 364 feet span being $1,622, the cost of a truss of 520 feet would be more than twice as great per lineal foot, according to the above extract, or $3,244 per lineal foot, or $1,686,880 for the whole span.

If we introduce the same prices for the same materials, used in this estimate, into the estimate for the ribbed arch of 515 feet span, as far as applicable, and allow the same percentage for contingencies, we obtain the following comparative estimate of cost of superstructure for an arch of 515 feet clear span :

Cast Steel	848 tons in arch,	$820 00	$271,360 00
Wrought Iron	158 "	240 00	37,920 00
Rolled Iron	374 "	180 00	67,320 00
Cast Iron	61 "	140 00	8,540 00
Cast Iron in Roadway	7 tons,	140 00	980 00
Spikes, Bolts, etc	34 "	150 00	5,100 00
Pine Timber	196,000 feet,	8	15,680 00
Oak Timber	23,000 "	10	2,300 00
Nicholson Pavement	191 squares,	35 00	6,685 00
Galvanized Iron Lining	26,500 sqr. feet,	20	5,300 00
Railing	1,060 lineal feet,	8 00	8,480 00
Cornice	1,060 "	1 50	1,590 00
Painting			12,000 00
Raising			20,000 00
Testing and Engineering			45,000 00
Contingencies, 25 per cent			127,063 75
Total			$635,318 75

Or, $1,233 per lineal foot of Bridge.

The cost of a ribbed arch of 500 feet span would therefore be $616,500, or $1,070,380 less than the cost of a truss of the same span on the plan approved by the Convention.* It may be said that

* I have no doubt that the substitution of steel in the upper and lower members os the truss, and in its struts and braces, would make this comparison more favor-

the prices in the truss estimate are higher than those at which the work could be executed. This may be true, but on the other hand the estimate for the ribbed arch here given is $154,263 more than the actual estimate of its probable cost to be found in another part of this report, and which is based on proposals from reliable parties. By the latter estimate its cost per lineal foot is $934.09.

Comparison of the Cost of Superstructure (from Levee to Levee) of the Bridge, approved by the Board of Civil Engineers, with the Cost of Superstructure of the Arch Bridge:

The Bridge approved by the Board of Civil Engineers consists of two trusses of 368 feet each, and four trusses of 264 feet each (from levee to levee).

The cost of a 364 feet truss, as before stated, is $1,622 per lineal foot, and the cost of a truss of 244 feet span is, according to the same estimate from which the above figures are quoted, $243,805.51, or $1,000 per lineal foot. Even assuming that the cost of a truss of 264 feet span (for which we have no estimate) would be the same per lineal foot as that of a truss of 244 feet, while it evidently would be more, the cost of superstructure of the truss bridge (between levees) would then be:

2 Trusses of 368 feet ($1,622 per lin. foot)	$1,180,992 84
4 Trusses of 264 feet ($1,000 per lin. foot)	1,056,000 00
Total cost of superstructure	$2,236,992 84

Your Bridge requires, between levees:

1 Span of 515 feet ($1,233 per lin. foot)	$ 635,318 75
2 Spans of 497 feet ($1,233 per lin. foot)	1,225,602 00
Total cost of superstructure	$1,860,920 75

or nearly $400,000 less than the truss bridge approved by the Convention.

If, instead of the two trusses of 368 feet span, and four trusses of 264 feet span, one truss of 500 feet span and five trusses of 244 feet

able for the truss, but it would still be greatly in favor of the arch. I give the figures, however, as used in estimates made for the actual construction of the two systems; by Mr. Post for the one, and by myself for the other, when there was no probability of the two estimates being used in comparison.

The proof of the greater economy of the ribbed arch over the truss in superstructure, as explained in *this report* under the head of *Arch and Truss*, is clearly demonstrated by this comparison, though it is proper to state that the portion of the report under that heading was merely designed as a general illustration of the principles involved, without aiming at mathematical accuracy. In the Appendix the investigations for the Bridge are set forth in a manner to challenge the most critical scientific analysis.

span each had been adopted, the cost of superstructure would have been as follows:

1 Span of 500 feet	$1,687,000 00
5 Spans of 244 feet ($1,000 per lin. foot)	1,220,000 00
Total cost of superstructure	$2,907,000 00

or $670,000 more than if built on the plan recommended by the Board of Civil Engineers, and $1,046,000 more than on the plan adopted by you.

That the cost of a 500 feet truss is not stated too high in the above comparison is proved by the statement contained on page 43 of the Report of the Board of Civil Engineers, that the construction of the truss bridge, with a span of 500 feet, would involve an extra cost of about three-fourths of a million of dollars ($750,000), while, according to the figures adopted in our comparison, the difference is $670,000 only.

I have no means of knowing the exact estimate for the substructure of the truss bridge, but it is stated, on page 82 of the Report, at $2,541,007. The estimated cost of the substructure of your bridge, including its approaches, is $2,060,477.24.

SUSPENSION AND UPRIGHT ARCH BRIDGES.

Although great difference of opinion exists among engineers as to the safety and durability of suspension bridges, and also as to their fitness for railway purposes, I believe they very generally, if not unanimously, agree that, for long spans, that method of bridging is of all others the most economical.

It is because of this acknowledged economy of the suspended arch in bridge construction that I propose to draw a comparison between it and the upright ribbed arch, and to support with a few undisputed facts the proposition (based upon recent investigations of the compressive strength of cast steel) that an upright arched bridge for railway trains may be *more economically* constructed with cast steel by the method adopted in your Bridge, than is possible with the suspended arch, the length of spans in both cases being equal, and both being required to possess the same ability to resist deflection. This comparison will, I think, vindicate my reasons for not wishing to adopt the suspension principle in your Bridge.

When iron or steel is subjected to any strain, either tensile or compressive, the material is lengthened or shortened in proportion to the force exerted. When released from the strain, it resumes its original length, unless the force exerted exceeded its limit of elasticity. If this occurs, the material receives what is called a *permanent set*. In proportion as the piece under strain is lengthened, its

diameter is reduced. When permanent set occurs, it fails to recover its diameter as well as its length. Its ability to sustain a repetition or continuation of tensile strains, after loss of diameter occurs from permanent set, is proportionately lessened, and by frequently repeating the load that produced it, the material will be fractured. Sometimes a less one will, after a few repetitions, break the metal. When the piece is subjected to compressive strain, these conditions are reversed. The piece is shortened under the action of the force, and its diameter is increased. Permanent set, by increasing its diameter, increases to a certain extent its ability to resist the same force repeatedly applied.

If from any cause (for instance, an error in workmanship) a member be subjected to a tensile strain beyond what it was designed to bear, such strain may exceed the limit of elasticity, and sooner or later it will snap asunder, and possibly cause the destruction of the Bridge. This was probably the reason why the Bollman truss (a rigid suspension bridge) gave way at Zanesville recently, under a much less load than it had been tested with, precipitating a locomotive and train into the river below. This could not occur with a member in compression, for if its length were so proportioned (as it should be) to its diameter as to insure crushing or permanently shortening without bending, the piece would be shortened by the extra strain, but would still perform its duty safely, as long as any other member of the structure.

We have no proof that iron or steel, when under compression, are any more liable to fracture by sudden jarring than when at rest; or that their strength is at all impaired by vibration when under compression. We do know, however, that they are more liable to fracture by sudden jarring or concussion when under tension, that their strength is impaired by continued vibration under tension, and that the liability to fracture by sudden jarring under tension increases with the increase of strain. The careful engineer, when using these materials in tension, will therefore leave a large margin within the elastic limit for safety; but for compressive strains he may base his calculations on using them to the full limit of elasticity with entire safety. Cast iron is shown by Rodman to take a permanent set with 7,000 pounds pressure, and many kinds with much less, and yet it is used in bridge construction by eminent engineers to 10,000 and even to 12,000 pounds on the square inch in compression; while wrought iron is rarely used in tension beyond 10,000 or 12,000 pounds, although it will stand from 18,000 to 25,000 pounds before permanent set occurs.

Cast steel being much more homogeneous, and capable of being manufactured of any given quality with much greater certainty than cast iron, we are more fully justified in using it in compression up to the limit of its elasticity than we are in using cast iron.

By rolling and hammering cast steel, its strength is greatly increased. By tempering it in oil, Kirkaldy found its tensile strength increased 79 per cent. Hardening it increases the limit of elasticity of the material both for compressive and tensile strains, but also increases its liability to fracture by concussion when under tension. By being wire-drawn, it is possible to increase its ultimate tensile strength to 250,000 pounds to the square inch. Fairbairn's recent experiments prove its ultimate strength in compression to be two and one-tenth times greater than in tension.

The limit of elasticity of mild rolled steel is about 50,000 pounds, but it is ordinarily used only to 20,000 pounds by engineers for maximum tensile strains. By wire-drawing, it could probably be safely used to twice or thrice that strain. Hammered cast steel, designed for tools, when tempered, will sustain a crushing force of nearly 400,000 pounds, and its elastic limit will probably reach 120,000 pounds. It is possible that the steel prepared for stamping coins may considerably exceed that strength.

Experiments recently made at the Washington Navy Yard for me, through the courtesy and under the careful supervision of Chief Engineer Wm. H. Shock, U. S. N., Chief Engineer of the yard, show the elastic limit of sixty-eight samples of rolled cast steel under compression to average 55,008 pounds, and eight samples of rolled cast steel, each one inch in diameter and twelve inches long, to average 75,197 pounds per square inch. This steel was all of the ordinary tool steel of commerce, and made in Pittsburgh.

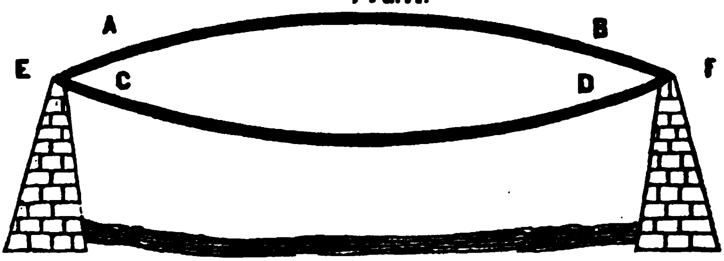
These facts show that the elastic limit of cast steel is greater in compression than in tension, and that this limit can be increased by proper manipulation of the material, for compression as well as for tension; and that we can use its full limit in compression, while we dare not go much beyond one-half of it in tension. How much the available difference is, in the present state of our knowledge of the manufacture and treatment of the material, will only be shown by careful experiment to discover the steel best suited for each use. Enough is known, however, to assure us that the limit of elasticity is higher in compression than in tension, and if it were no greater, we cannot avail ourselves of more than 50 or 60 per cent. of this limit in tension, while the whole of it can safely be utilized in compression.

I will now proceed to examine whether there be any conditions involved in the use of the upright ribbed arch that will counterbalance the advantage to be gained by using the material in compression.

This investigation involves the inquiry, *firstly:* will the structure require more material by using the upright arch than the suspended one: and if so, how much more? And *secondly*, will its construction and erection be more costly?

If the upright arch, A B, and the suspended one, C D (Fig. 11), be each supported upon the points E F, and are each of the same form and weight, the compressive strain throughout the upright arch will be exactly equal to the tensile strain throughout the suspended one. The weight of the upright arch will exert no more power to force the points E F asunder than the weight of the suspended arch can exert to pull them together. Hence, the tensile strain borne by the metal of the suspended arch at C and D must be exactly equal to the compressive strain on that in the other at A and B. These facts being incontrovertible, it follows that if the upright arch be made of a material whose compressive strength is twice as great as its tensile strength, it will with equal safety sustain, with one-half of the material, as great a load as the suspended arch, so long as the form of its

FIG. 11.



curve is preserved; because a bar of cast steel one inch square will safely sustain only 25,000 lbs. if the weight be *suspended* by it, while it will safely sustain 50,000 lbs. if it be placed *under* the load in the manner of a post or column. If steel were but one-half stronger in compression than in tension, then two-thirds of the material only would be required to give the same strength in the upright arch that would be required for the suspended one. In that case, an upright arch having 1,000 tons of cast steel properly disposed throughout its length, would sustain as great a load as 1,500 tons in the suspended form. (To avoid complicating the explanation, we will consider the weight of the bridge itself, and the load it bears, together.)

I admit that the upright arch must be more thoroughly braced than the suspended one, but we should in this instance have 500 tons of material to spare for this purpose, between the abutments alone, for the steel does not cease at the towers in the suspended arch, but continues on over them, and usually half a span beyond them on each side, to the anchors; whilst with the upright arch it stops at the abutments.

The advocates of the suspension principle will assert that the influence of gravitation maintains the suspended arch in position against

lateral movement, while the same influence would cause the other to topple over. This is, however, only true where but one rib of the arch or one cable is used, and only affects the argument where the arch is greatly disproportioned to the width of the Bridge. The ingenious device to give lateral stability to suspension bridges will be equally effective in imparting it to the upright arched bridge of great span. The method adopted is to keep the points from which the cables are suspended widely separated, while the latter are drawn more closely together at their points of greatest depression. This is a reversal of the method proposed by Telford for his great cast-iron arch over the Thames, as the conditions in the suspended arch are exactly reversed. The ribs forming the upright arch, where the span is very great, would be placed widely apart at the abutments, and from thence would gradually incline toward each other until the summit of the bridge is reached. By spreading the arches at their bases, and fastening them to the abutments, we obtain even greater security against lateral flexure in the upright than in the suspended form, for each rib of the upright span springing from the masonry acts as a rigid brace, held at its lower extremity by the weight of the abutment, and is competent to resist either tension or compression. In this case, resistance to lateral flexure would come from the weight of the abutments, while in the suspension bridge, it comes only from the gravity of the suspended mass—the resistance of the floors or horizontal bracing being the same in both cases.

The upright arch requires to be thoroughly braced to prevent a change of form under the moving load, as the flattening or straightening of any part of the curve in it tends to decrease its strength, whilst the curve of the suspended arch may be changed in a greater degree without endangering the structure. For railroad purposes, however, this could not be permitted in the suspended arch to any considerable extent.

In the upright arch, the parts lying between the centre and the abutments, called the haunches, mutually balance each other, and the imposition of a load on either haunch, if the arch be flexible, causes the other to rise, while the one sustaining the load is proportionately depressed. When this change of its form occurs, the centre of the arch moves horizontally toward the unloaded side; but if we prevent the centre of the arch from moving horizontally, the haunch cannot be depressed with the load equally distributed over it, except to the slight extent that is caused by the shortening of the steel under the compressive force exerted by the load. This movement is prevented by dividing the mass of the arch into an upper and lower member, and bracing these so effectually that their relative positions to each other cannot be altered under the severest strains to which they can be subjected. This gives stiffness to the haunches, and when one is loaded it is not only supported by its own rigidity,

but by that of the unloaded one also, because the one cannot be bent downwards without bending the other upwards, and therefore the effect is really the same as though the load on one haunch was borne by two arches of but half the real span. This stiffness prevents the horizontal movement of the arch at the centre, and this is further prevented by securing the upper roadway of the Bridge to the crown of the arch, by which any horizontal movement of the arch would be transmitted through the roadway and resisted at the abutments.

The moving load affects the equilibrium of the suspended arch less than the upright one, but it nevertheless disturbs it to an extent that requires a certain amount of bracing to prevent it from changing the form of its curve; and therefore all the bracing required for this purpose by the upright arch must not be counted against the latter in comparing the relative economy of the two systems.

Mr. Roebling says: "Wire cables, if guarded against oscillations, and not exposed to an undue tension, may be looked upon as of indefinite durability. Severe friction, short bending, constant vibration, high tension, and frequent shocks, will soon wear out the best material. The more we can reduce these exposures, the greater will be its durability." To preserve a suspended arch against ultimate destruction, it is therefore important to maintain its form against repeated alterations as far as possible.

The difference in the cost of erection of the arches would be considerably less for the suspended one than the other. The ribbed arch, however, can be erected without the use of false works beneath it, and is of all systems (except the suspension) the most cheaply erected. The ribbed arch with fixed ends may be self-sustaining for more than one-fourth of its length from each abutment, and the remainder can be put together by suspending it from cables supported on small temporary towers upon the abutments. It would be unnecessary to have these cables of a size sufficient to bear much more than the upper or lower member only of the rib beyond the point at which the arch would be self-sustaining. If that were completed before the other one was put up, it would then aid in sustaining the other members required to finish the arch. The upright ribs would require to be braced from one to the other laterally, which would not be necessary if they were suspended. This, however, lessens the amount required in the roadways, while the lateral bracing required in the roadways of the suspension bridge cannot be much less.

The greater cost of the erection of the upright arch could not possibly equal the cost of the greater quantity of material required in the suspended one between the towers. As was before stated, however, the excess of material required for the arches or cables of the suspension bridge is not confined to that required in the arches be-

tween the towers, for these cables must be carried nearly or quite half the span beyond the towers on either side to the arches, while the upright arch ceases at the abutments. This is more clearly shown in the accompanying wood cuts. The material required to extend from one anchor, and over the towers to the other one, is usually double the length of the suspended arch, and it must be of equal cross section or diameter with that between the towers. If it be less than double the length, the portion beyond the towers must be greater in sectional area. Now, if the tensile strength of the steel be available to the extent of but half what it would be in compression, and double the length of material be required in the suspended arch to reach from anchor to anchor, it must follow (excluding all question of cost of bracing the two systems) that there will be four times as much material required from anchor to anchor in the suspension principle as is needed in the upright arch between the abutments.

It will be claimed that the extension of the cables beyond the towers gives support for the approaches. This, however, utilizes but a small portion of their cost, for a much less expensive method of approaches is almost always practicable.

In the item of masonry, the upright arch has the advantage, as a glance at Figs. 12 and 13 will prove. If we assume that the two spans between the abutments and the towers are of equal weight, and the rise in one arch be equal to the deflection in the other, then the compressive force at A B is just equal to the tensile force at C D, and as the cables rest upon movable saddles on the towers, the tensile strain at C D will be the same at E F. This pulling strain at E F is therefore just equal to the thrust or compressive strain at A B. It will, consequently, require the same resistance to counteract it that will be required at A B to resist the thrust of the arch, with this important difference—that the thrust of the arch is a *downward* pressure, tending to add weight to the masonry below the arch, and thus increase the friction of the mass (which is its element of resistance), while the strain of the cable is an *upward* one, and is in the direction to diminish this resistance. Assuming that the masonry required for the abutments be equal to what were required for the anchorage of the suspension bridge, then the masonry contained in the two towers supporting the cables will be that much more than the upright arch requires. Of course these propositions will be more or less favorable to either system in different localities.

If it were admitted that the material could not be used in compression with any higher value of strength than in tension, we would still be able to provide the excess of bracing required in the upright arch, and the difference in the expense of erecting it, at less cost than is incurred by the other system, because of the necessity of carrying the cables beyond the towers; and we would in that case still effect a saving in the cost of masonry by using the upright arch.

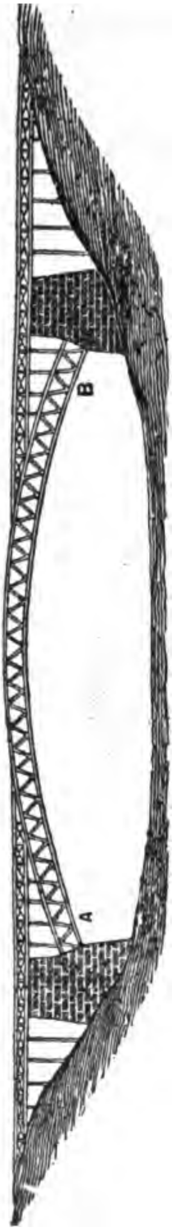


Fig. 12.

Fig. 13.

In the cost of construction there can be but little difference. If an extraordinary high tensile strength be obtained in the steel to economize the quantity required, it would probably be used in the form of wire, and this would increase the cost of fabrication. In the form in which I propose to use it, three-fourths of the quantity required will be used almost as it comes from the makers, in bars about nine feet long, each weighing about 130 pounds, and three cents per pound extra will pay for finishing it ready to go into the structure.

I think all these facts clearly prove the economy of the upright ribbed arch over every other system of bridging with long spans.

The chief secret of the greater economy of iron suspension bridges rests in the fact that the limit of elasticity of iron wire is far greater in *tension* than the limit of elasticity for any form of iron known (except steel) when used in *compression*. Cast steel reverses this condition of things, and the adoption of it in bridge construction must result in reversing this advantage of economy and giving it in favor of the upright arch, and thus enable us to make spans of equal if not greater length, and with as great safety, as by the suspension principle. Mr. Roebling asserts that suspension bridges may be safely made of iron wire of half a mile span, and that when steel is used in their construction nearly double this span may be accomplished with equal security.

MANNER OF USING THE STEEL.

To obtain the highest value of cast steel in compression, with the greatest economy in construction, I think it should be used in the tubular form. Although cast steel tubes have been recently drawn cold by hydrostatic pressure in France, from steel expressly prepared for the purpose, I cannot learn that the process has been carried to any extent beyond the production of gun barrels. It is quite possible that this method may in the future furnish steel much superior for bridging to anything we can now obtain. I have but little doubt that methods of manufacturing and tempering steel in this form, for bridge construction, will soon be discovered, by which a much higher value of strength may be safely used in construction. As the use of cast steel in bridge building is comparatively in its infancy, I have deemed it proper to use the material at a much safer limit as regards its ultimate strength than my judgment would otherwise dictate. I feel assured that the structure would be entirely safe to bear a far greater load than can be placed upon it, if its arches contained but one-half of the steel that will form them. When this material comes to be universally used in bridge construction in the place of wrought and cast iron, as it inevitably will be because of its greater

economy, the very large margin for safety provided by the liberal use of this material in your Bridge will be more fully appreciated.

To insure a uniform quality and high grade of steel at the lowest prices, and at the same time avail myself of the advantages of the tubular form of construction, I propose to have the steel rolled for the arches in bars of nine feet length, and of such form that ten of them shall fill the circumference of a nine-inch lap-welded tube 1 inch thick, in the manner that the staves of a barrel fill the hoops. This would virtually form a steel tube nine inches in diameter and of six inches bore, the steel being about 1½ inches thick, and would be much less expensive than if the tube were rolled or drawn in one piece. The manufacture of the steel in such small bars will insure a more uniform quality in the metal, and in the tube each bar will be supported against deflection in every direction. The tubes will be retained in their positions by an effective system of bracing, which will sustain the *voussoirs*, or pieces against which the tubes are butted throughout the arch. The upper and lower members of each arch will each be formed of two courses of these tubes, from end to end of the arch, each tube having a sectional area of thirty-six square inches at the summit of the arch. As each span would be made up of four arches, and each arch of four of these tubes, the span would have an aggregate sectional area at that part of 576 cubic inches of steel. The tubes, for about twenty feet of their lengths nearest the abutments, would require one-half more sectional area to resist the greater strains at those points. The tubing in which the steel bars would be inclosed would effectually protect the latter from the weather.

I am gratified in being able to state that proposals from several of our leading steel makers in the United States have been received, and also from some of the most celebrated in Europe, among whom I may name Naylor & Co., of England; Petin, Gaudet & Co., of France; and Fred. Krupp, of Prussia; all offering to furnish the steel, and agreeing to guarantee its strength fully up to the standard required.

The importance of being guided by the very best lights that can be obtained from practical and careful experiment, and the great interests involved in the safety and permanency of the structure, fully convinced me, at the inception of this enterprise, of the necessity of instituting a careful series of experimental tests of the materials to be used, and also determined me to have every part of the structure thoroughly tested to a degree of strain much beyond what it can by any possibility be subjected to when in the Bridge.

For this purpose I am having a powerful machine made, that will be capable of carefully testing every member used in its construction.

ESTIMATE OF COST OF THE BRIDGE.

I. SUPERSTRUCTURE OF BRIDGE.

One Arch of 515 feet span.

848.05 tons of cast steel, in ribs, at $320	$271,376 00
158.12 " wrought iron, in ribs, at $200	31,624 00
378.99 " rolled iron, in ribs, at $140	52,858 60
60.56 " cast iron, in bed plates, at $80	4,844 80
196,000 feet, b. m., pine timber and plank, at $50 per M	9,800 00
23,000 " oak " " at $70 per M	1,610 00
191 squares Nicholson pavement, at $20 *	3,820 00
34 tons of spikes, bolts, etc., at $120	4,080 00
7 " cast iron, in roadways, at $80	560 00
26,500 square feet lining, of galvanized iron, at 20c	5,300 00
1,060 linear feet of railing, at $6	6,360 00
1,060 " cornice, at $1 50	1,590 00
Painting	12,000 00
Raising	20,000 00
Testing	12,000 00
Engineering and contingencies, 10 per cent †	43,732 34
Total	$481,055 74

Or $934.09 per linear foot.

Two Arches of 497 feet Span.

The cost of these two spans was calculated from the same data as the span of 515 feet, and was found, including 10 per cent., or $84,983 56, for contingencies, to amount to $934,819 16

Anchor Rods between Skewbacks.

126 tons of cast steel, at $240	$30,240 00
32 " cast iron (plates), at $80	2,560 00
Contingencies, 10 per cent	3,280 00
Total	$36,080 00

Superstructure on Piers and Abutments.

16.4 tons of rolled iron, in beams, at $120	$1,968 00
35,000 feet, b. m., pine timber, at $50 per M	1,750 00
9,000 " oak timber, at $70 per M	630 00
50 squares Nicholson pavement, at $20	1,000 00
391 linear feet iron railing, at $6	2,346 00
Contingencies, 10 per cent	769 40
Total	$8,463 40

* The cost of the plank floor on which the blocks of the pavement rest is estimated separately.

† The contingencies have been estimated at only 10 per cent. in this case, because, as before stated, the prices for material and workmanship in the estimate are based on actual proposals received from reliable parties.

Summary of Cost of Superstructure.

One span of 515 feet	$481,055 74
Two spans of 497 feet each	934,819 16
Anchor rods	36,080 00
Superstructure on piers and abutments	8,463 40
Total cost of superstructure	$1,460,418 30

II. Substructure.*

Caissons, piles, and coffer dam	$182,700 00
Sinking caissons and machinery	65,000 00
Dredging and pumping	87,600 00
Coffer dam for west abutment	18,000 00
5,178 cubic yards concrete, at $8	41,424 00
55,318 " limestone masonry, at $14	774,452 00
3,784 " sandstone masonry, at $15	56,760 00
5,102 " granite masonry, at $32	163,264 00
Engineering and contingencies, 15 per cent	200,880 00
Total	$1,540,080 00

III. Approaches.

12,000 cubic yards earth excavation, at 35c	$ 4,200 00
200 " rock excavation, at $1.50	300 00
3,292 " limestone masonry, in approaches over levee, at $14	46,088 00
8,237 " sandstone masonry, at $15	123,555 00
1,244 " granite masonry, at $32	39,808 00
133 " cut sheeting, at $16	2,128 00
793 " coursed rubble, at $9	7,137 00
4,738 " rubble masonry, at $7	33,166 00
518 " brick arch, at $12	6,216 00
2,907 " brick masonry, at $10	29,070 00
559 " concrete, at $7	3,913 00
20.7 " dimension stone, at $20	414 00
3,802 " broken stone ballast, at $2	7,604 00
1,440 linear feet piling, at $1	1,440 00
121.95 tons cast iron, at $80	9,756 00
307.5 " wrought and rolled iron, at $140	43,050 00
1,188 linear feet railing, at $6	7,128 00
1,200 " " in trestle, at $6	3,600 00
487 " upper roadway (including lining, etc., and Nicholson pavement), at $40	19,480 00
816 linear feet upper roadway (including lining), at $31	25,296 00
518 " lower roadway, at $22	11,396 00
371,458 feet, b. m., pine timber and plank, at $50 per M	18,572 90
68,150 " oak plank, at $70 per M	4,770 50
Stairs, etc.	10,000 00
Station on Third street, and entrance	15,000 00
Contingencies, 10 per cent	47,308 84
Total	$520,397 24

* The masonry is all under contract, at prices below those introduced into the estimate.

IV. Tunnel.*

118,460	cubic yards	earth excavation, at 35c	$ 41,461 00
14,400	"	refilling, at 20c	2,880 00
4,272	"	concrete, at $7	29,904 00
16,498	"	brick arch, at $12	197,916 00
2,380	"	coursed rubble, at $9	21,420 00
58	"	coping, at $40	2,320 00
4,024	"	ballast, at $1 50	6,036 00
Sewers			35,000 00
Land damages, ventilators, etc			20,000 00
Contingencies and engineering, 15 per cent			53,540 55
Total			$410,477 55

V. Land and Damages.

Between Levee and Main street	$147,400 00
" Main street and Second street	205,500 00
" Second street and Third street	187,000 00
Total	$539,900 00

VI. Railroad.

2.14 miles of railroad track over bridge and through tunnel, at $12,000	$25,680 00

Summary.

I.—Superstructure of bridge	$1,460,418 30
II.—Substructure	1,540,080 00
III.—Approaches	520,897 24
IV.—Tunnel	410,477 55
V.—Land and land damages	539,900 00
VI.—Railroad	25,680 00
Total	$4,496,953 09

ESTIMATE OF REVENUE.

In order to correctly estimate the amount of revenue which an enterprise of such character as a Bridge designed to accommodate ten different railroads, and the local requirements of two populous cities, is likely to yield, the official figures, as given and reported by the different railroad companies, the imports and exports of this city, as published by our Chamber of Commerce, and all the information which could possibly be obtained by our most prominent dealers in coal, and by the different express and transportation companies, were consulted and taken as proper and reliable data.

*The tunnel is 4,800 feet in length; the open cut south of Clark avenue, 700 feet.

Assuming that the Bridge will be completed in 1871, a proper estimate of its revenue could be made only by taking the revenue which would have been derived from the commerce and travel which crossed the river at St. Louis in 1867 as a basis upon which to calculate the *prospective* revenue which will be derived in 1871, when the Bridge will be actually finished.

The following are the principal items from which a revenue can be derived: Tonnage, coal, railroad passengers, foot passengers, farmers' teams, horse railroads, pleasure carriages, cattle, etc.

RAILROAD FREIGHT AND TONNAGE.

The freight forwarded to and from St. Louis during the year 1867 by three different railroads which have their termini at East St. Louis is as follows:

	Tons.
St. Louis, Alton and Terre Haute	484,685
Ohio and Mississippi	333,175
Chicago, Alton and St. Louis	249,550
Total tonnage	1,067,410
From which deduct *Coal*	300,000
Total Merchandise	767,410

COAL.

The quantity of coal brought to East St. Louis by rail does not all cross the river. A large portion is loaded into barges, and by them discharged directly into steamers lying on the Levee, and another portion is tranferred by barges to this side of the river, from whence it is loaded into wagons and distributed among the factories and through the city generally. The largest portion is, however, brought over directly by wagons.

The Illinois and St. Louis Railroad and Coal Company delivers about 250,000 bushels of coal per month on the eastern side of the river, of which 150,000 are sold directly to steamboats, and 100,000 are transferred in barges to the city, and from these it is loaded into wagons. The first item, being a direct transfer to steamboats, does not enter into our calculations, but it is fair to presume that of the 100,000 bushels per month which are transferred in barges, and have to be loaded into wagons and pulled up the steep Levee, one-half at least would be loaded into wagons directly from the cars and cross the smooth, level Bridge with great saving to the teams, as well as in wear and tear of wagons.

Assuming, therefore, that of the whole 250,000 bushels per month,

only 50,000 will cross the Bridge, we have 600,000 bushels per annum crossing by wagon, at 115 bushels to a four-horse wagon, making 5,217 teams.

One of our largest dealers and owners of coal mines delivers seven and a half millions of bushels in this city, and the other large dealers combined about two and a half millions, making ten millions of bushels; all of which cross by wagon.

Assuming that if the Bridge had been finished, and one-half of this quantity (five millions) had been brought over in railroad cars, and the other half only by teams, we would have, at 80 pounds to the bushel, 200,000 tons; and for the other half, at 115 bushels per team, 43,477 teams, making the total of coal crossing the Bridge 200,000 tons in bulk, and 48,694 teams.

RAILROAD AND FOOT PASSENGERS.

The railroad passengers in 1866 (figures of 1867 could not be obtained) coming to and from St. Louis, were 479,200. It is safe to estimate that 2,000 foot passengers would have crossed the Bridge per day, making per year, 700,000.

FARMERS' TEAMS.

There were brought by wagons across the river in the year 1867:

Wheat	355,320	bushels.	20,000 teams.
Barley	10,000	"	350 "
Corn	72,650	"	6,000 "
Oats	10,000	"	350 "
Rye	7,600	"	300 "
Flour	127,771	barrels.	15,593 "
			42,593 "

Allowing an average of only 100 farmers' wagons per day crossing and recrossing with vegetables, fruits, etc., we can add 36,500 teams, making a total of 79,093 teams.

HORSE RAILROADS AND PLEASURE CARRIAGES.

A double track horse railroad through the upper roadway of the Bridge, carrying an average of 1,000 passengers daily, passing through the principal portion of East St. Louis, and connecting with the numerous lines centering at Third street and Washington avenue, in this city, will be in constant operation. Of pleasure carriages, hotel, express, and baggage wagons, an estimate of one hundred per day is much below the present intercourse between the two shores.

CATTLE.

There were imported and exported to and from St. Louis in 1867, by three railroads alone, as follows:

Ohio and Mississippi Railroad	6,874 cattle.
" "	82,183 hogs.
" "	15,184 sheep.
Chicago and St. Louis Railroad	19,293 cattle.
" "	76,118 hogs.
" "	85,496 sheep.
St. Louis, Terre Haute and Alton Railroad	2,234 cattle.
" " "	37,561 hogs.
" " "	19,705 sheep.

Total—Cattle, 27,901; hogs and sheep, 176,292.

RECAPITULATION OF SUPPOSED REVENUE FOR 1867.

767,400 tons railroad freight, at 60 cents per ton	$460,440
200,000 tons coal, at 30 cents per ton	60,000
48,964 four-horse coal teams, at 50 cents	24,482
479,200 railroad passengers, at 5 cents	23,960
700,000 foot passengers, at 3 cents	21,000
79,093 farmers' wagons, at 50 cents	39,546
Horse railroad	20,000
Pleasure and hotel carriages, express and baggage teams, buggies and horsemen	50,000
27,901 cattle at 10 cents	2,790
176,292 hogs and sheep, at 3 cents	5,289
	$707,507
To which should be added tunnel toll, 500,000 tons at 10 cents	50,000
Total supposed Revenue of 1867	$757,507

A comparison of the present charges for transportation, made by the Ferry and Transportation Companies, and those that will be made by the Bridge Company, results as follows:

1. The present charge by the Transportation Companies for common merchandise in wagons is *six cents* per hundred pounds, or *one dollar and twenty cents* per ton, exclusive of city cartage, for which three cents extra is charged. The Bridge's charge will be *sixty cents*, making a saving of *100 per cent.* on each ton of merchandise.

2. Each four-horse coal team pays $1 on the ferry. The proposed charge on the Bridge is 50 cents.

3. Railroad passengers now pay 50 cents each, inclusive of city transportation of their baggage. After the Bridge is finished, they will pay only five cents for crossing into the heart of the city, and will then select the cheap horse railways, or their own mode of transportation to their respective residences.

4. Each foot passenger on the ferry now pays five cents. On the Bridge the charge will be three cents, and the delays incident to the ferry will be avoided.

5. Farmers' wagons are now charged 50 cents. The Bridge's charge will be 40 cents.

6. The charge for cattle is now 12½ cents; for hogs and sheep, four cents. The proposed charges are ten cents and three cents respectively.

ANNUAL SAVING TO COMMERCE.

Had the commerce of St. Louis in 1867 passed over the Bridge, the following amounts would have been saved to our merchants and the community:

Sixty cents difference in transporting 767,400 tons merchandise	$460,440
Reduction of 10 per cent. in the price of coal, on ten million bushels, at 15 cents	150,000
The loss to commerce through total interruption on account of ice is certainly not less than	100,000
The cheapening of fruit, garden vegetables, and feed	50,000
480,000 railroad passengers, at 25 cents	120,000
Making a total of	$880,440

The above amount would have been saved to the community in 1867, if a bridge had been in operation at that time. In 1871, when it will be finished, the saving to our citizens will amount to millions.

This estimate of revenue being based on statistical figures, official data and the most reliable information, without recourse to fantastic or high-wrought ideas, or imaginary profits, and giving a plain statement of the commerce and travel across the Mississippi opposite our city during the year 1867, brings us to the consideration of the

PROSPECTIVE REVENUE

of the Bridge after its completion in 1870 or 1871. It is barely possible for the mind to keep within cool, calculating bounds when contemplating the future of St. Louis, with her unbounded resources and unrivaled situation. Located in the centre of a valley of exhaustless fertility, on a river which traverses the continent, and on which hundreds of steamers are constantly engaged in pouring the treasures of that valley into her lap, she is now extending her railroads westward, northward, and southward, and will, by the time the Bridge is completed, become the recipient of countless stores of metals, coal, lumber, cereals, hemp, tobacco, and cattle, the products of the favored regions which her extended railroads are approaching.

The Southwest Pacific and Iron Mountain Railroads are now in the

hands of capitalists with ample means, and will in the course of two years be finished,—the one through the fertile prairies of Southwest Missouri to the rich lead mines of Granby, and on to the Gulf of Mexico; the other through the Iron Mountain, Pilot Knob, Washington, and St. Francis mines, to connect with the Southern system of railroads opposite Columbus and Memphis. The North Missouri, now within thirty miles of the State line, will soon enjoy an unbroken railway communication with St. Paul. Its West Branch will also connect with the Union Pacific Railroad, Eastern Division, within the month of November next, and perhaps in twelve months more, with the Union Pacific at Omaha; this, with the Missouri Pacific already connected with the Union Pacific, Eastern Division, secures to St. Louis the two great trunk lines which run to the Pacific Ocean. The point of intersection of these trans-continental railways, with a majestic river flowing from the frozen regions of the North almost to the Tropics, may be compared to the grand cross-roads of the American Continent. This intersection is made almost at the centre of the most magnificent system of inland navigation in the world, and almost in the very heart (whether considered geographically, or with reference to the extremes of climate) of the largest and most fertile valley on the earth. At this point St. Louis is located, and her future can scarcely be over-estimated.

The construction of this Bridge will stimulate the production and fabrication of iron, encourage the erection of manufactories of all kinds, and invigorate the whole industrial and commercial life of the city. It will make the thriving city of East St. Louis a large and populous manufacturing place, where the artisans of this city can find cheap homes, and by which the intercourse between the two, amalgamated in interest, will be kept in constant activity. The consumption of coal and its transport across the Bridge will be enormous, and no more embargoes by ice, which sometimes isolate us from the East, render our ferries useless, and raise the price of fuel five-fold, will be suffered to palsy commerce and entail distress upon the poor.

Taking all these facts into consideration, it is safe to assume that at the time when this Bridge will be finished, and the completed railroads will pour all their wealth of mineral and produce into our lap, to be transported East across the Bridge, while the East again will send the products of her industrial establishments and factories westward across the same highway—when peace and prosperity will add a fresh impulse to enterprise and commerce—that the ratio of increase in 1871 will be at least 50 per cent. over that of 1867. Nothing invites commerce so much as facilities of transportation; nothing invites population so much as facilities of communication. The receipts and revenues of the ferry company afford not the remotest criterion by which to calculate the prospective revenues and receipts of such a Bridge. They can only be depended upon as establishing a

minimum estimate, for we might as well calculate the prospective receipts of a railroad by taking as a basis the tolls of a country turnpike along which it passes.

Counting, therefore, 50 per cent. increase as a perfectly safe basis, the receipts of the Bridge would be $1,136,260 in 1871. Calculating the receipts of the Bridge, however, when first opened to be only one million of dollars, it will show the following financial results:

Total cost of Bridge, Land, and Approaches (estimated cost being $4,496,953), say	$4,500,000
Interest at 6 per cent., *gold*, for two years on half the sum	270,000
Premium on gold, 40 per cent	108,000
Total cost	$4,878,000

RESOURCES.

4,000 bonds of $1,000 each, bearing 6 per cent. (gold) interest, at "$950," (5 per cent. discount)	$8,800,000
Full paid stock	1,000,000
Remnants of valuable strips of land available after condemnation*	150,000
	$4,950,000

REVENUE.

		1867.	1871.
From all sources as stated above		$757,507	$1,000,000
Less interest	$270,000		
" premium on gold	108,000		
" 1 per cent. sinking fund †	40,000		
" office salaries	20,000		
" repairs	20,000		
" taxes, police, etc	10,000		
		$468,000	$468,000
Leaving a surplus on estimate of 1867		$289,507	
" " " 1871			$532,000

It will be readily seen that, resting even on the incredible assumption that the receipts of the Bridge will not exceed one million of dollars for the next thirty years, the bonds will all be paid, and the Bridge be free of debt at the expiration of that time. In the estimate of expenditures, the item of 40 per cent. premium on gold is included, amounting to $96,000 annually, which is to diminish gradually and with certainty, and will cease entirely when specie payment is resumed.

Whatever shape the financial policy of the Company may assume, I feel safe in stating that rarely has an enterprise been inaugurated

* This amount is much below what will likely be realized from the sale or rent of condemned property, which will remain in strips, unavailable for bridge purposes, but of great prospective value.

† An annual sinking fund of $40,000 at compound 6 per cent. interest, will realize in thirty years $4,376,816, sufficient to pay off the whole bonded debt.

which appeals so strongly to the support of our citizens of all classes, which promises so much to add to the welfare and prosperity of the city, and which offers such a safe and remunerative return for the labor and capital invested in it.

CONCLUSION.

The contract for the entire masonry of the Bridge has been awarded to Mr. James Andrews, of Allegheny City. This gentleman has had great experience in similar undertakings, and enjoys a high reputation for skillfulness, energy, and faithfulness in the prosecution of his contracts. The masonry thus far executed has been constructed by him under this contract.

I am under many obligations to Mr. Wm. H. Shock, U. S. N., Chief Engineer of the Navy Yard at Washington, for the very careful and interesting series of experiments with cast steel made by him for this work at my request. Those experiments were made with the testing machine used by Col. Rodman, U. S. A., in his well known experiments on cast iron for cannon. The results obtained by Mr. Shock have been before alluded to in this report, and are very valuable as defining the limit of elasticity in the various samples of crucible cast steel tested by him, thus giving assurance that by using the steel in the manner I propose doing, we are far within the limits of safety.

The work in the drawing room has been chiefly executed by Mr. Wm. Rehberg, C. E., and the remarkable neatness and precision observed by him in this important part of the work, has relieved me of much care, and entitles him to the kind consideration of the company.

The first stone in the construction of the Bridge was laid upon the bed rock of the river, within the coffer-dam inclosing the site of the western abutment, on the 25th of February, 1868, in the presence of the President, Directors, and several of the Stockholders of the Company, and of the Mayor, Hon. Jas. S. Thomas, and many other prominent citizens of St. Louis.

I cannot close this report without availing myself of the opportunity it affords of expressing my grateful appreciation of the unwavering confidence and support I have received from the Directors and Stockholders of the Bridge Company, from its inception to the present time, during which period the plans adopted by you have been subjected to a degree of public and private criticism and misrepresentation rarely attending such enterprises.

Respectfully submitted.

Your obedient servant,

JAMES B. EADS.

Engineer's Office Ills. & St. Louis Bridge Co.,
June 1st, 1868.

REPORT

To the President and Directors of the Illinois and St. Louis Bridge Company, September 1, 1869.

Gentlemen,—I have the honor to report the following facts respecting the progress of the work on your Bridge, the preparations for sinking the two channel piers, and expenditures to date.

The western abutment has been carried up five feet above low-water mark. This masonry is laid within the coffer-dam completed in the early part of 1868, and is founded on the rock twenty feet below low-water mark. Work upon this abutment was suspended last winter, and has not been resumed since because of the continued high water. Three thousand and sixteen cubic yards of masonry have been laid in this part of the work. Operations on it will not be resumed this fall unless a sufficient amount of stone can be obtained for that purpose in excess of what will be needed for the two channel piers. The amount required for the latter is so great as to make this improbable.

On the wharf the foundations for two of the piers in the western approach have been put down on the rock and completed to the wharf level. The amount of masonry contained in them is 433 cubic yards.

On the resumption of operations by the Company last May, the desire was expressed by the Directory that an effort should be made to put in not only the larger pier this fall, but the western one also. I explained to the Board that to do this would create the necessity of duplicating nearly all the floating machinery, engines, barges, etc., required for the eastern pier, and that this would involve an outlay of at least $150,000 more than I had stated would be necessary for building the masonry ten feet above low-water mark. I stated also that it would involve the absolute necessity of calling upon the stockholders for a more rapid payment of their subscriptions than at the rate of five per cent. every sixty days, as had been agreed upon. It was thought, however, that as the completion of the Bridge at a much earlier date would be insured thereby, a greater saving in interest would be effected by such earlier completion, in addition to which would be the advantage of an earlier receipt of its revenues. This extra outlay, closely estimated from contracts and actual payments

made to date, amounts to $142,300. It will not really increase the ultimate cost of the work more than 50 or 60 per cent. of this amount, as a large part of the sum will be returned by a sale of the machinery, etc., after the completion of the masonry. It was believed also by the Directory that it was the general desire of the stockholders that the work should be pushed to completion with the utmost energy. I was therefore instructed to undertake the sinking of both piers this fall. Preparations for this purpose were at once begun, and every effort has been made to insure their completion from the rock to ten feet above low-water mark before the ice sets in. Although three weeks of unexpected delay has occurred, caused by an almost unprecedented continuance of high water, I still feel confident of accomplishing the work before interruption from ice occurs. I have, however, made such provision, in the event that it is not completed by that time, as will save the Company from any considerable loss from damage by ice.

The height of the eastern pier when completed ten feet above low-water mark will be 97 feet, and that of the other 69 feet, above the rock. About 78 feet in depth of sand will be encountered in sinking the one, and 50 feet in the other, with about 20 feet of water on the site of each pier. The base of each pier is 82 feet long—the eastern one being 60 feet wide, and the other 48 feet wide. The larger one will cover an area of 4,020 square feet, and the other 3,360 square feet. At ten feet above low-water mark each pier is 78 feet in length by 38 feet in width, and at that point each one will contain a sectional area of 2,600 square feet. The amount of masonry, brick work and concrete required to be laid to bring these piers from the rock to the required height above low water is about 20,800 cubic yards.

To construct two piers of this magnitude in the brief space of time named, and under the natural difficulties mentioned, requires very complete machinery and appliances, and ample preparations for every contingency that can be foreseen.

Stone in large quantity must be prepared, and so assorted that the desired sizes can be rapidly transported to the work as they are needed, and the most simple, reliable and expeditious means provided for hoisting and transporting them to their positions in the piers.

The unusual depth to be reached, and the magnitude of the piers, caused me to devote the most serious consideration to this part of the work, to determine the most reliable method of accomplishing it. Every published authority of note, in English, French and German, was consulted upon the subject, and finally a method was devised by which I was fully satisfied the work could be certainly and safely executed. This method was explained in my published report on the Bridge, May, 1868. Plans and detail drawings in accordance with it were with great care and labor matured, with the intention of adopting it; but during my visit to Europe last winter I had an opportunity

of witnessing the operation of sinking masonry piers by the *plenum pneumatic* process, as practiced by the engineers on the continent of Europe, and I there became satisfied that with the improvements made in it by them, many of which are unpublished, I could sink the piers of your Bridge quite as safely, as expeditiously, and more economically, than by the method I had intended to use. In France and England I was so fortunate as to be permitted to exchange views upon this subject with several of the most distinguished engineers in the profession, and my opinions upon this, the most important question in the construction of your Bridge, were fully confirmed as a result of those interviews.

In adopting this method of sinking the piers it was necessary to mature plans and details of an entirely new type for the necessary caissons and floating appliances, and to design and construct machinery, purchases, etc., quite different also from what had been intended.

These designs have been carefully matured, and the requisite caissons and machinery contracted for. The larger caisson is nearly finished, and considerable work on the smaller one is done. Nearly all of the machinery has been completed, and a large part of it is already in place, and has been satisfactorily tested. The remainder will be all ready as soon as required. Some idea of what has been accomplished may be gathered from the following statement:

BOATS FOR PUMPS AND MACHINERY.

Two large boats, the *Allen* and *Johnson*, intended for the eastern pier, and two others, the *Alpha* and *Omega*, for the western one, have been prepared for the following machinery, to be used in sinking the piers:

Six large steam boilers have been placed on the *Allen*, and six others on the *Alpha*, arranged four in two double batteries, and two in two single batteries in each boat. These are all complete, and steam has been raised on all of them.

AIR PUMPS.

Four air pumps, 4 feet stroke and 14 inches diameter of cylinders, driven by two independent engines, 24-inch stroke and 20-inch diameter of cylinders, have been designed and constructed and placed on the *Allen*, and the same number on the *Alpha*. Those on the *Allen* have been tried, and proved entirely satisfactory. Those on the *Alpha* are nearly ready for trial.

MACHINERY FOR LAYING STONE

Frame works have been designed and prepared for all four of these boats for supporting the travelers with which the stone and materials will be transferred from barges to the piers, and that for the *Allen* and *Johnson* is already erected on them. This frame work is about fifty feet high, and supports six wire cables, two and one-fourth inches diameter, on each boat, and upon each cable is arranged a traveler for hoisting and transporting the stone, etc. Each traveler is capable of transporting a seven-ton stone one hundred feet. These travelers are arranged to be worked by hydraulic rams when hoisting and lowering the stone, and by simple gearing when transporting it. Four engines, one on each boat, have been provided and placed in position for working these twenty-four travelers, and the shafting and gearing required for them is all in position. Twenty-four hydraulic jacks, of 10 feet stroke and 5 inch diameter, have been made ready, and are being rapidly placed in position on the four boats, for the hoisting of the stone; and six hydraulic rams, required for supplying them with water, at a pressure of 1,600 pounds per square inch, are finished, and are being placed on the boats.

Each one of these travelers will be completely controlled by one man; and with them twelve stones, each of seven tons weight, can be raised and placed in position in each pier at one and the same time. The *Allen* and *Johnson* are intended to be fixed, one on each side of the eastern pier, and to lift stone on to the pier from barges outside of them. These arrangements for handling stone are so complete and simple in construction and rapid in movement that I think it practicable to lay an average of ten thousand cubic feet of masonry, or two and one-half feet of the pier in height, per day. With them the stone can be supplied as fast as it is possible for it to be laid, three minutes being all the time required to make fast to the largest one on a barge and place it at the hands of the mason over the spot it is to occupy in the pier. Fourteen thousand seven hundred and eighty feet of wire rope will be used for these twenty-four travelers, and nearly all of it is ready, and the large cables are in place on the *Allen* and *Johnson*.

SAND PUMPS.

Seven sand pumps will be used in the caisson of the eastern pier and five in the western one, for removing the sand as the piers descend. These pumps are of very simple, but novel construction, never having been used before. One of three-inch bore has been thoroughly tested on the site of the Bridge, in forty feet of water, and found capable of discharging ten cubic yards of sand per hour. Fifty-four cubic feet of sand were delivered by it from that depth in eleven min-

utes. Gravel stones as large as could enter it (two and one-fourth inches in diameter) were discharged by it with as much facility as sand. As there are no working parts in its construction, it seems scarcely possible for it to get out of order. The principle on which the pump acts is somewhat similar to that of Giffard's Injector, water being used instead of steam. A stream of water is forced down through one pipe and caused to discharge near the sand into another in an annular jet, and in an upward direction. The jet creates a vacuum below it, by which the sand is drawn into the second pipe or pump, the lower end of which is in the sand, and the force of the jet drives the sand on upward to the surface of the river as soon as it passes through the annular opening in the jet.

The superiority of this pump over all others capable of pumping sand and gravel, with which I am acquainted, consists in its being supplied with the requisite quantity of water for keeping the sand in a fluid condition, whilst the suction pipe is inserted directly into the sand. With other pumps the quantity of sand cannot be regulated, and it is liable to be drawn in in such quantity as to choke up the pipes and working parts of the pump, the water drawn in with the sand not being sufficient to keep it fluid. The weight of the column set in motion by the pump is consequently liable to constant variation, as it has more or less solid material in it; and when the column is raised by atmospheric pressure (vacuum), and a lift of only twelve or fifteen feet attempted, the pump may cease to lift the column, it being so much heavier than water, because of having so much sand in it. In this case, if the suction pipe has a foot-valve at the lower end of it, as most centrifugal pumps do, the sand falls back on it and the pipe must be taken out to empty it of its contents. When too much sand is in the column above the ordinary pumps, the pipe is liable to be overloaded with it, the action of the pump ceases, and the contents must be removed before the pump will again work. If the water jet in the pump described fails to discharge the sand, no choking up of the pump can occur. There is nothing in the construction of it to prevent the sand from running back when the jet stops, and if the jet is strong enough it will raise it to any height. The one experimented with worked admirably, even with the end of the pipe nineteen feet deep in the sand and forty feet depth of water over the sand. The vacuum obtained by the jet with the pump out of water, and the lower end closed, supported twenty-eight and three-fourths inches of masonry, the vacuum being almost perfect.

The pipes used in the pumps for the caissons will be of five-inch bore. About 2,500 feet of this pipe will be required for this purpose. These pumps are nearly completed, and will be ready as soon as required. Five powerful steam pumps are required to drive these sand pumps, and they have been provided for, and part of them have been placed on board and satisfactorily tested.

The importance of avoiding in a work of this kind the many inconveniences and delays which dredging machines would be liable to cause, if required to lift sand from seventy-five to one hundred and ten feet in height, in immediate proximity to extensive masonry operations, will be readily appreciated by all engineers.

From numerous borings made on the site of both piers to the bed rock, I am satisfied that coarse and fine sand with a few strata of gravel, constitute the only materials to be removed.

These sand pumps, hydraulic rams, air pumps, and gearing for the travelers on the *Allen* and *Alpha*, will all be driven by the six large boilers on each of those two boats; and two portable engines will be used on the *Johnson* and two on the *Omega* for working the travelers on each of those boats. These are also provided for. A large amount of india-rubber hose and wire tubing will be used to convey the compressed air from the air pumps to the air chambers of the caissons, all of which has been provided.

BREAKWATERS.

Two large steam pile drivers have been constructed to put down piles to form breakwaters above the site of the piers, and the work on the eastern one was commenced about the 12th of August. This work was delayed much later than was intended by the extraordinary continuance of an unusually high spring flood. The driving of the piles was commenced in 47 feet of water, with a subsiding river, but in a few days thereafter another rise of five feet, which covered the tops of the piles then driven, caused the work to be again suspended.

To understand the cause of this delay correctly, it must be stated that the effect of high water in the narrow gorge of the river opposite this city, across which the site of your Bridge is located, is to accelerate the current and scour out the sandy bottom of the river. As the river subsides the current becomes less impetuous, and a fresh deposit of sand takes the place of that which was scoured out. The present stage of water has created a scour of eighteen to twenty feet. Ordinarily, at this season of the year, we should have had ten or twelve feet less water, and perhaps fifteen feet less scour. This would have given us from twenty-five to twenty-seven feet less depth of water to work in, which would have greatly facilitated the work. The water is now about twenty feet above low-water mark, and the current is nearly six miles per hour. The river is seven feet higher now than it has been at this season of the year for many years before. The unusual depth of water was not the only cause of detention, as longer piles and more labor would have overcome that difficulty; but during a rise of the river, when the water is already very high, such quantities of drift-wood are floated down that it is almost impossible to anchor the pile-driving boats in it. The river is again falling,

however, and work on the eastern breakwater has been resumed, with a depth of 48 feet. By the 15th inst. I expect this work will be so far completed as to enable us to begin the other one. These breakwaters are intended not only to defend us from rafts, and other floating things before winter sets in, but to protect our works from ice in the event of our being delayed in getting the piers to the rock before it flows. Later in the fall they will be filled with rip-rap stone, and be made otherwise capable of resisting the ice. They will be 150 feet above the site of the piers.

The caisson for the larger pier has been delayed about two weeks in its completion, for the want of iron and rivets. These difficulties are now, however, removed, and I think it will certainly be ready to take its place in the river by the 25th inst. The other will be completed and ready to be towed into position by the 20th of October. The contract for constructing these caissons was awarded to Mr. William S. Nelson, of this city, at 4 cents per pound, the Company furnishing the iron and rivets. The contract for the iron was awarded to Messrs. Gaylord, Son & Co., of Cincinnati, at 5⅛ cents per pound. The contract for the rivets was given to the Norway Iron Manufacturing Company, of Wheeling, at 6 cents per pound. About 570 tons of plate and angle iron will be furnished by Gaylord, Son & Co., and the remainder being the upper portion, will be obtained from the iron hull of the U. S. gunboat Milwaukee. This vessel was purchased last winter from the Salvor Wrecking Company for $14,000, being about 2½ cents per pound. The contract of Mr. Nelson requires him to cut up and work in the plate iron of the hull of the vessel, in the construction of the caissons, at the same rate as the new iron. This iron is one-fourth and three-eighths inch thick, and it is estimated that there will be 200 tons obtained from the vessel, leaving about 120 tons of scrap and other iron, not useful to the Company, for sale. The price at which the hull was purchased, taken in connection with the contract requiring Mr. Nelson to use the iron, will result in considerable saving to the Company.

AIR CHAMBERS.

The air chambers of both caissons are nine feet in height, and their sides are formed of ¾-inch plate iron in the larger, and ⅝-inch in the smaller one. The designs of both caissons are quite similar, except that the smaller has but five air locks; and the plate iron used is somewhat lighter than in the other. A description of one (which must necessarily be brief) will answer for both. The air chamber is simply a huge diving bell beneath the pier, being of the full size of the latter. Its roof is required to sustain the enormous weight of the entire pier from the rock to the surface of the water, and must be

of such strength as to prevent any change of form, as that would endanger the cracking of the masonry before it had been finally bedded upon thc rock. As we shall have to work, in all probability, with the river not less than ten feet above low-water mark, and perhaps twenty feet, the masonry resting on the roof of the air chamber in the large caisson will be nearly one nundred feet high when the bottom of the air chamber reaches the rock. The iron plates forming its roof are of ½-inch thickness. Transversely over this are placed thirteen iron girders, which are securely riveted to it at intervals of 5½ feet. Each girder is five feet in height, and is made of ½-inch plate iron, with a top chord of 5x7½ inches. The spaces between them will be laid with masonry. Beneath the roof are placed two massive wooden girders in the opposite direction to the iron ones, and these latter divide the area of each chamber into three nearly equal parts. Communication between these three divisions will be had through openings made for this purpose through these girders. These timber girders are intended to rest upon the sand and support the roof from below, thus giving support to the iron girders at equidistant points in their length. The sides of the air chambers are strongly braced, to resist the pressure of the sand, with plate-iron brackets stiffened with angle iron. Between the brackets, near the bottom, is placed all around the chamber a course of strong timbers, the bottom of which is level with that of the girders, and which are also designed to rest upon the sand. The area of bearing surface of this course of timber, and of the two girders in the larger caisson, is 850 square feet. The support given by this surface resting upon the sand, together with the buoyant power of the compressed air in the chamber and the friction of the sand on the sides of the caisson, are the only means relied upon to sustain the pier in its gradual descent to the rock Workmen and superintendents will see that the sand is evenly excavated, by which means the vertical position of the pier will be maintained. As in the diving bell, the bottom of the air chamber is entirely open, and the water is prevented from rising within it by the compressed air forced into it. A false bottom is placed under it, by which it is converted into a kind of boat, and in this way the caisson will be floated and towed to its place in the river.

MANNER OF SINKING THE CAISSONS.

The caisson will be held in place by fourteen large guide-piles, each 3½ feet in diameter, and all strongly braced together. Ten large screws, each 25 feet long, and supported by these piles, will regulate the descent of the caisson and prevent any tilting of it until it reaches the sand. The sides of the air chamber extend two feet below the timber girders within it, and form a cutting edge always that

much in advance of the bearing surface of the wooden girders, which are seven feet in height. This arrangement will more effectually counteract any tendency in the caisson to move horizontally in descending. When secured within the guide-piles, and attached to the large screws above-mentioned, air will be forced into the air chamber, the false bottom then removed from under it, and the laying of masonry will be immediately commenced over the roof of the air chamber. The walls of the caisson will be extended up ten feet above the roof of the air chamber before being towed into position, and they will be built up from time to time by riveting on additional plates as the caisson sinks by the weight of masonry laid within it.

The weight of the masonry will be sustained by the buoyancy of the air chamber and caisson until the latter reaches the sand, the screws being only relied on to keep it steady until it enters the sand. The guide-piles and screws sustaining the caisson are all ready for use, and the placing of guide-piles in position will be commenced on the 13th inst.

AIR LOCKS.

The large caisson will contain seven air locks, through which to obtain entrance to and exit from the air chamber for men and materials. The air locks have heretofore been placed above the surface of the water, and ingress and egress to the chamber obtained through large vertical iron pipes leading through the masonry. In these caissons the air locks are placed within the roof of the air chamber, and access will be had to them through brick walls or air shafts built up in the masonry over them, by which a very important saving in cost will be effected, the delay in constantly adding new joints of pipe under the air locks as the pier descends avoided, and greater convenience attained in introducing materials and workmen into the chamber.

The air locks are circular vertical chambers, about five feet in diameter, and of various heights—from six to twelve feet. They are made of ½-inch plate iron. They are provided with two doors, one opening into the open air and one into the air chamber. The first door in opening swings into the air lock, and the other into the air chamber. The fact that the air chamber is filled with compressed air involves the necessity of one or the other door being closed to prevent its escape. Either one being closed, the pressure of the air tends to keep it closed, but leaves the other free. The inner door being closed, we enter the air lock through the outer one, and close it behind us. A cock is then opened communicating with the air chamber, and the air lock is immediately filled with compressed air. This equalizes the pressure on both sides of the inner door, and it can at once be opened, and we then enter the air chamber. To return to the

open air we re-enter the air lock, close the inner door, and then open another cock, which allows the compressed air in the lock to escape. This relieves the outer door of the pressure that was on it, and it can at once be opened for our exit. One door or the other is always free to open. To open both doors at once in thirty-three feet of water would require an enormous force (about ten thousand pounds) to be applied to the one on which the air pressure was acting at the time. This gives great security to those within the air chamber against the carelessness or ignorance of others passing in or out.

The question of the ability of human beings to work at the depth of one hundred feet below the surface of the water has been settled by the fact that divers in submarine armor have descended and worked in much greater depths. The air chamber will be much less fatiguing to them, as the diver is relieved of the labor of moving his armor with every movement of body or limb, a labor which increases with the depth attained, and which becomes very great at sixty or seventy feet.

POSITION OF SAND PUMPS.

The sand pumps are placed on the roof of the air chamber, and their suction pipes extend down through the air chamber into the sand. Telescopic joints on the lower ends of these pipes allow them to be extended into the sand to the required depths. The sand lying out of the reach of the pumps will be washed to them by a jet of water from a flexible hose supplied by a forcing pump. Every effort has been made to reduce the number of men required within the air chamber, and to perform as much of the requisite work as possible by steam power. This will expedite it and reduce the cost of it, as the wages paid to those working in the air chambers are usually twice as great as to those employed on other parts of the work. From four to six men at a time will be all that will be needed within the air chamber as it descends. When it reaches the bottom the sand will be removed from the rock, and the chamber will then be carefully filled with concrete, after which the air shafts will be filled.

MASONRY.

The masonry of the piers will be of magnesian limestone, from the Grafton quarries, laid in Louisville cement, in courses of from eighteen to thirty inches in thickness. From two feet below low-water mark up to high-water mark the exterior of the piers will be of quarry-faced granite.

The contract for all the masonry is made with Mr. James Andrews, who has now delivered at St. Louis about 1,800 cubic yards of cut stone for the face, and upwards of 2,000 cubic yards of backing. The

cut stone is being piled on the levee at the site of the Bridge, the use of about 1,000 feet front of the wharf having been given to the Company by the city for that and other purposes. The backing is piled at the river bank near the foot of Lami street, about a mile below. To facilitate and expedite the unloading of the stone, fourteen derricks have been erected along the levee near the foot of Washington avenue, which are, with the exception of two, operated by horse power; and at the foot of Lami street two steam derricks, together with four horse derricks, are in operation. Two more steam derricks are ready to be raised.

There have also been laid at these two points 3,000 lineal feet of railroad track, in which fifty-eight tons of railroad iron have been used. These tracks are partly laid in trestle-work running out into the river, so that, when the laying of masonry is commenced, barges which carry the stone to the site of the piers can receive their loads with the necessary dispatch. A great portion of the stone will, of course, be delivered at the piers immediately by the barges from the quarries forty miles above, while the stone stored at St. Louis forms a reserve, in case of interruption of the navigation between Grafton and St. Louis by low water or ice.

In the quarries at Grafton upwards of two hundred men are employed in quarrying and dressing the stone; and the facilities for handling the stone there have, within the last four weeks, been very largely increased by the erection of suitable machinery, so that the quarries will shortly be able to furnish and ship six hundred cubic yards of cut stone and backing per day. Two traveling derricks, three derricks for loading and two floating derricks, are in operation, and two double-inclined railways carry the stone to the river bank. Two more of the latter are under way and will be completed in a few days. Besides these derricks, there are two suspension wire cables with travelers, with engines ready to go into operation; and an engine for operating four more travelers on cables is also on the ground ready to be set up. The machinery at the quarries is furnished by the contractors.

The towing of the barges is performed by the Grafton Stone and Transportation Company, under a contract with your Company; and the cost of delivery is about fifty cents per cubic yard.

The barges for carrying the stone are supplied by the Bridge Company. Each is capable of transporting from 150 to 250 cubic yards of stone at a trip. Eleven have been purchased and fitted up and are now in use.

A contract was made with the Richmond Granite Company, early in June, for the delivery of 700 cubic yards of granite, at 78½ cents per cubic foot, delivered on board of vessels at Richmond, Va; and three courses are now ready for shipment, an inspector having gone to Richmond to receive them.

A contract has been made with the Hydraulic Press Brick Company for 350,000 best quality of hard-burnt brick for the air shafts, at $9 50 per thousand. A large part of these have been received.

Two thousand two hundred barrels of cement are stored in the Company's warehouse, and a contract has been made for 2,000 more. Ten thousand barrels will be required by the first of December, and contracts for the remainder will soon be closed.

BLACKSMITH AND MACHINE SHOP.

To enable us to make repairs and to do the lighter kinds of iron work without going to the shops, a small frame building was put up on the levee in the Company's yard, at the foot of Washington avenue, and the necessary tools placed therein. It contains three forges (all supplied by a revolving fan) and one drilling and one screw-cutting machine. The necessary power is furnished by a portable engine.

OTHER MACHINERY.

A wood-planing machine, belonging to the Bridge Company, is now at work in Carondelet, planing the timber for the caisson girders.

The machinery used in laying the stone for the western abutment, and consisting of ten travelers, is yet used for unloading barges, and is driven by a separate engine.

A testing machine, large enough to test up to 100 tons, is under way. The castings are already made, and we are only waiting the arrival of some steel parts, already shipped from New York City, to set it up. This machine is supplied with a hydrostatic press to adapt it to pieces of different lengths, but the strain is measured by a system of levers, instead of being determined, as usual, by a pressure gauge secured on the hydrostatic cylinder. It will test specimens of a length not exceeding four feet both in tension and compression. In designing it, however, care was taken to permit its being lengthened so as to test the longest pieces which may be used in the superstructure of the Bridge.

RIVER CRAFT.

Besides the boats and barges before mentioned, the Company owns the propeller W. H. Hewitt, used for towing and transportation about the harbor, and also three coal flats, three caulkers' flats and two large yawls.

INSTRUMENTS, ETC.

The Company has a fair supply of surveyors' instruments and a

full set of boring tools, which latter have been used very successfully in determining the depth of rock on the site of the piers.

MATERIAL ON HAND.

Besides the stone, cement, brick and iron which have been mentioned above, there is a large quantity of squared timber, piles and plank on hand, destined to serve in the construction of the two piers and of the eastern abutment.

EXPENDITURES.

The account of expenditures herewith submitted is furnished by the Auditor of the Company, Mr. George C. Fabian, and shows the total amount of expenditures, of every kind whatever, to the first of September, 1869, to be $851,603 31.

In this connection I will state that from careful estimates recently made, and based in great part upon actual payments made to date, and contracts being now performed, I am entirely satisfied that the cost of constructing the masonry of your Bridge to ten feet above low-water mark will be less than the estimates hitherto made for it, and considerably less than those contained in my published report of May, 1868, notwithstanding the additional expense involved by putting in both piers at once.

CONCLUSION.

Since the middle of last June at least 1,000 men have been constantly employed in the work of preparing to put down the two channel piers, and the number now daily employed on it is probably not less than 1,500.

My grateful acknowiedgments are due to each and all of the gentlemen associated with me in the engineering and construction departments of the work for the zealous and effective co-operation given by them to me in their several departments. Especially are they due to Col. W. Milnor Roberts, Associate Chief Engineer, who was appointed by the Board to take charge of the work on the occasion of my being compelled by ill-health last July to visit Europe. His earnest interest for the success of the enterprise has been manifested from the moment of his connection with it. His able counsels, based upon large professional experience and excellent judgment, were solicited by me upon all important matters connected with the work in hand, and have been of much value to me and advantage to the Company. Last June a very thorough examination of the principal granite quarries on the Atlantic seaboard was made by him. The contract closed with the Richmond Granite Company for the granite

required this season was the result of that examination, that Company proving to be the best and lowest bidder.

Respectfully submitted.

JAMES B. EADS, *Chief Engineer*.

REPORT

TO THE PRESIDENT AND DIRECTORS OF THE ST. LOUIS AND ILLINOIS BRIDGE COMPANY, OCTOBER 1, 1870.

GENTLEMEN,—I have the honor to submit the following report:

THE WEST ABUTMENT.

The masonry of the west abutment has been completed from the bed-rock of the river to a point thirty-one feet above low-water mark. From the bed-rock to the top of the masonry the height is now forty-four feet. Eight courses of granite are laid on it and two courses, or five feet, are required to complete it to the skewbacks against which the steel ribs of the western span will rest. This mass of solid masonry stands upon the lower edge of the wharf in St. Louis, and measures at its base, in the direction of the river current, ninety-four feet, and transversely sixty-two feet nine inches, and contains at this time 6,380 cubic yards of masonry. When completed to the carriage-way it will be 115 feet high, above the bed-rock of the river, and will then contain 11,860 cubic yards of masonry.

The work on it is going steadily forward in a satisfactory manner.

Although the bed-rock at the site of this abutment is seventy-three and a half feet higher than at the east pier, the difficulties encountered in building its foundation were of a much more perplexing and tedious character than those encountered at either of the others. Its site had been for over sixty years a part of the steamboat wharf of the city, and as such had received every kind of useless material thrown overboard from the various steamers lying over it during that time. The old sheet-iron enveloping their furnaces, worn-out grate-bars, old fire-bricks, parts of smoke-stacks, stone coal cinders and clinker, and every manner of things entering into the construction

of a Mississippi steamer, seemed to have found a resting-place at this spot, and constituted a deposit averaging twelve feet in depth over the rock. During the memorable fire of 1849, when twenty-nine steamers were destroyed at the levee, the wrecks of two of them sunk upon the site of this abutment. One of these was partly covered by the hull of the other, which probably sunk immediately afterwards. The lower one was but two or three feet above the bed-rock. After this terrible conflagration the city authorities determined to widen the wharf. Its front was extended to a line inclosing about one-half of these two wrecks, by filling in with stone and rubbish from the city. During this extension, several other vessels were burnt at the wharf, and the wreck of one of these also sunk upon the site of the abutment. The coffer-dam, constructed to enclose the site, had to be put down through these three wrecks, the hulk of either of which was not probably less than four hundred tons measurement. Their bottom planking was all of oak, three or four inches in thickness. To drive the sheet piling down through these hulks, an oak beam, six by ten inches square, armed with a huge steel chisel, was first driven down as far as a steam pile-driver could force it. It was then withdrawn and a sheet-pile, five by ten inches square, was driven down in its place. The coffer-dam was formed of two courses of sheet-piling, six feet apart, which were filled in between with clay. When this was completed, the water pumped out and the excavation prosecuted within it, the discovery was made that from one-third to one-half of the length of each of these three steamboat hulks was inclosed within the dam, and that some of the sheet-piling had not been driven through the lower one, owing to the great resistance of the hulk and the mass above it. Before the space between the lower wreck and the bed-rock could be made secure on the inner side of the dam, the water came through and flooded the inclosure. A stream from a powerful Gwynne pump, having an eight inch diameter of jet, was then directed against the material deposited over these wrecks on the outer side of the dam, where the water was fifteen feet deep, and enough of the deposit was washed away to enable another course of sheet piling to be driven down six feet beyond the dam, through all of the wrecks to the rock. After this, that part of the wrecks enclosed between this last course of piling and the dam, was removed by a diver and the space filled in with clay, and the inclosure again pumped out. This portion of the dam, about fifty feet in length, was by this construction made double. As the excavation within progressed, it revealed the fact that another portion of the dam had been built and made water-tight through and over a water-wheel of one of the wrecks. The crank of an engine of seven foot stroke attached to the head of the shaft of the wheel was just within the inclosure, while the flanges, arms

and braces of the wheel were within the walls formed by the sheet-piling. From the inclosure within the dam were taken parts of several old and burnt steamboat engines, the iron parts of some of which had to be cut off at the dam. Four wrecks of barges, some of them in use doubtless before the era of steam, were also found within it; likewise several oak saw-logs, some anchors, chains and a great variety of smaller articles lost or thrown overboard from the river craft, or dumped in from the city.

This incongruous deposit made it exceedingly difficult to maintain the integrity of the dam, which at times had to resist a pressure of thirty feet of water. Frequent floodings consequently occurred, which delayed and increased the cost of the work. These difficulties were, however, finally overcome, and the bed-rock within was at last exposed to view.

On the 25th day of February, 1868, after thoroughly testing the solidity of the rock by drilling, the first stone of your Bridge was laid in this abutment fifty-five feet below high-water mark, about four months after commencing the construction of the dam.

THE EAST PIER.

The caisson for sinking the east pier, described in my published report, September 1st, 1869, having been completed, and the requisite guide piles, air and sand pumps, hoisting machinery, etc., being made ready, it was launched from the ways at Carondelet on the 18th of October, 1869, and was towed up to its position in the river and duly secured within the guide-piles on the same day. Some days more were occupied in securing the caisson to the suspension screws that were to steady it until it reached the sandy bed of the river, and in connecting the various air and water-pipes with it. On the 25th day of October the first stone was laid upon it, from which moment until it reached the bed-rock of the river, on the 28th of February last (one hundred and twenty-eight feet below high-water mark, or one hundred and twenty feet below the city directrix), the progress of its descent and the working af the machinery connected with it were marked by an almost total freedom from accident.

During low water the normal depth of sand over the bed-rock at this pier is about eighty feet. A rise in the river causes it to scour down, whilst a subsidence of the flood permits the moving sands from above to deposit rapidly and again raise the sand bed. At the time of placing the caisson in position the water in the river was thirty-five feet deep, and sixty-eight feet of sand were then overlying the rock. As the caisson descended, the current sweeping under

its bottom at the rate of about three and a half miles per hour, caused a further scour of five feet, leaving an irregular surface of sand averaging about sixty-three feet deep above the rock. When the caisson had fairly entered the sand a deposit was made rapidly around it, especially in the eddy created below the caisson. The sides of the caisson were swept to some extent by the current, otherwise the derrick boats on each side of it would have grounded on the deposit. This deposit was increased by the discharge from the sand pumps, and by the completion of the ice-breaker above the pier, so that for twenty or thirty days before it reached the rock the sand was visible above the water, both above and below the caisson. The iron walls of the caisson had consequently a severe external pressure upon them from this mass of sand, and as the sides of the pier were inclined whilst the walls of the caisson were vertical, a space was left between the two. This space was at first occupied with bracings against the masonry to sustain the walls. As the pier descended and the pressure increased, sand from the pumps was discharged into it and in this way the walls were relieved, the height of sand inside, between the caisson walls and the pier, being maintained at the level of the sand on the outside. The design was to keep the masonry constantly built up above water, as the pier descended. The failure of the granite company to deliver in time the granite which was intended to form the exterior of the pier above low water mark, prevented me from following out this design. At the time the granite was wanted the river was from ten to twelve feet above low-water mark, and there was left only the alternative of stopping the descent of the caisson that much above the bed-rock and awaiting the recept of the granite, or else allowing the pier to descend and trust to the walls of the caisson to exclude the water above the top of the pier. Three courses of granite, each two feet thick, were received in time, but when the pier reached the bed-rock the top of the masonry was about six feet below the surface of the water.

To prevent danger to the workmen in the air chamber, in the event of the walls of the caisson giving way under a pressure of water and condition of things deemed possible, but not expected, the shafts or wells through the masonry, by which access was obtained to the air locks which were at the bottom of the pier, were kept securely built up above the level of the water. On one or two occasions leaks occurred in the caisson walls, causing the top of the masonry to be flooded. But this precaution prevented a suspension of the work of filling the air chamber under the pier with concrete, in consequence of such accidents, as the shafts remained free of water. During the month of April, however, the river rose to within nine feet six inches of the City Directrix, and was nineteen feet six inches above the top of the masonry. From the moment the caisson touched the rock up to this time, the filling of the air chamber with concrete had been

progressing almost without interruption. When the water reached this point the walls of the caisson suddenly sprung a leak, and the pier was again flooded in a few moments. As the flooding of the pier usually increased the leakage in the shafts very much, it was not found practicable to continue work in the air chamber when it happened, if the depth over the pier exceeded a few feet. When this accident occurred, the men were immediately signaled to come up from the air chamber, then one hundred and ten and a half feet below the surface of the river. This they did with entire safety. A suspension of work on the pier was then ordered until the water should subside.

Examinations of the caisson walls were made by our diver, Captain Quigley, and careful soundings were made to ascertain the depth of the sand on the inside and outside of the caisson. It was then discovered that fifty-five feet in depth of the sand on the east side of the caisson (on the outer side) had been scoured away by the action of the current, the soundings showing but thirty-five feet of sand remaining above the bed-rock. This had reversed the strains on the caisson walls; the corresponding fifty-five feet of sand on the inside, between the pier and the caisson, had by its gravity burst out the eastern wall of the caisson, now no longer supported by the sand on the outside. This wall was of plate iron, three-eighths of an inch in thickness. This rupture rendered the further use of the caisson as a coffer-dam forever after totally impracticable. The upper portion of it was consequently removed, and in its stead there was secured around the pier a wooden dam, joined together in sections corresponding to the sides and ends of the pier, and having a large cushion near its lower edge, on the inner side, to fit against the fourth joint of the masonry below the top course of the pier. This work was admirably executed under the direction of the Superintendent of Construction, Mr. W. K. McComas, the submarine work being very skillfully performed by Capt. Quigley. On the 13th of August the water was again pumped off from the top of the masonry. Since this time the pier has been carried up to the height of one hundred and seventeen feet above the bed-rock on which it rests, and is now (October 1st) nineteen feet nine inches above the present level of the river surface. The coffer-dam has been removed from around it, and no apprehension of further trouble from water during its completion need be entertained. It measures at its base, in the direction of the current, eighty-two feet in length, and transversely sixty feet, and on the top, at its present height, seventy-five feet seven inches by thirty-five feet one inch. It now contains thirteen thousand two hundred and forty cubic yards of masonry, concrete and brick work. The vertical wells or shafts through it were lined with brick work from thirteen to twenty-two inches in thickness. These openings were carefully filled up with concrete, and the entire pier is now one solid mass of masonry.

In addition to the almost constant presence of the Superintendent of Construction, in charge of all the works, it was made the duty of three civil engineers, familiar with the plans, machinery, etc., to give their personal superintendence to the sinking of the pier; one being constantly on duty, watching the progress of the work, and keeping a record of everything of interest occurring. The necessary number of steam engineers, machinists and firemen were employed for keeping the engines at work night and day, and the machinery in perfect order, so that the work could go on without any interruption whatever. To accomplish this desirable object, sufficient duplicate pumps, engines, boilers, etc., were provided, so that the failure of any one piece of the machinery would cause no stoppage in the progress of the work. The pier was placed on the rock in one hundred and twenty-six days after the laying of the first stone, which period included the most inhospitable season of the year. The mason work was suspended during twenty days of this time on account of bad weather. During fifteen days it was impossible to tow a barge of stone to the pier on account of the running ice.

TELEGRAPH.

When the pier had reached the depth of sixty-six feet, a telegraphic instrument was placed in the air chamber, and a wire was led to the office of the Superintendent of Construction on one of the derrick boats at the pier, and also to the office of the Chief Engineer in the city. By this means messages were transmitted to and from the air chamber, and between the offices of the Superintenpent of Construction and that of the Chief Engineer, by which I was, when not present, regularly advised of the progress and condition of the work during the sinking of the pier. The knowledge that a means of communication with the upper world was constantly at hand in the air chamber, and one which was not likely to be interrupted by any accident endangering the lives of the workmen in it, was productive of a very salutaay moral effect upon them.

These telegraphic arrangements were courteously put up complete under the gratuitous superintendence of Col. Charles H. Haskins, General Superintendent of the Pacific and Atlantic Telegraph Company. The instruments were of the kind known as "alphabetical," and were easily understood and operated by those placed in charge of them in the service of the Bridge Company.

FILLING THE AIR CHAMBER.

The filling of the air chumber was executed in the most careful and substantial manner, under the immediate direction of the Superin-

tendent of Construction. The preparation and disposition of the concrete were made in the air chamber (from one hundred and three to one hundred and ten and a half feet beneath the surface of the river), under the immediate supervision of Mr. Rud. Wieser, C. E., Chief Inspector of Masonry, and his assistants, Mr. Rich. Richardson and Mr. Fritz Eberley, master masons, one or the other being constantly on duty. From frequent personal inspection, I am warranted in saying that this part of the work is unsurpassed in excellence by that of any part of the masonry above water.

The filling of the air chamber with concrete commenced on the 2nd day of last March, and was finished on the 27th of last May, the working time being fifty-three days. The space filled may be fairly stated at nearly thirty-six thousand cubic feet. The area of the base of the pier is four thousand and twenty square feet, and the height of the chamber nine feet. The caisson was stopped as soon as it touched the bed-rock. This was at its southwest corner. At the northwest corner its edge was eight inches from the rock. The northeast corner was sixteen inches and the southeast corner eight inches. It will be seen from this that the rock was, fortunately, very nearly level. The sand beneath the edge of the caisson was removed, the rock laid bare, and the space filled carefully with concrete, the air pressure being sufficient to prevent a more rapid infiltration of the water under the edge of the caisson than could be managed by the pumping arrangements within it. The sand seemed packed so firmly that no trouble was taken to barricade it out of this space between the rock and the edge of the caisson. When the entire edge of the caisson and the space under its two great girders were thus concreted, the rock in its interior was gradually cleared of sand and the concrete placed directly upon it in layers of nine or ten inches in thickness, the closing courses under the roof of the chamber being stoutly rammed in place. The air locks were then filled with the same material, and finally the shafts. The concrete was made of broken limestone, thoroughly washed, the interstices being filled with mortar made of equal parts of Akron cement and pure sand.

During the sinking of the piers the sand pumps designed by me for this special purpose gave great satisfaction, and proved entirely successful. One pump of three and one-half inches bore was found quite capable of raising twenty cubic yards of sand one hundred and twenty feet high per hour; the water pressure required to supply the jet being about one hundred and fifty pounds per square inch.

PRESSURE IN THE AIR CHAMBER.

The pressure of air in the air chamber was very accurately determined by the depth of the caisson below the surface. Any greater

pressure than that due to the depth caused the air to escape beneath it, but when the caisson had penetrated into the sand to a considerable distance, it was discovered that the water level formed by the air under or across the bottom of the chamber was nearly a foot lower than the bottom edge of the caisson. When the caisson was but a few feet in the sand, the air forced its way up by its sides in one or two currents of large volume, but as it penetrated more deeply, the passage of the air through the sand evidently became more difficult, and it appeared in small bubbles sixty or seventy feet distant from the caisson. This retardation of the escapement of the air from beneath the caisson, caused an increase of air pressure by which the water was held at a greater or lesser depth below the line of the bottom of the air chamber. The sand inclosed in the air chamber and forming its floor was usually one or two feet more elevated than the lower edge of the chamber, and was entirely devoid of water, the air pressure expelling the water from it down below the edge of the caisson as just stated. The distance to which it was thus expelled and maintained, was at no time discovered to exceed ten inches, and generally it was not over eight inches. This would give an air pressure equal to nearly one foot more than the depth of the caisson, or about one-third of a pound per square inch more. This difficulty of escapement of the air through the sand was increased somewhat by concreting under the edge of the caisson on the rock, and the actual air pressure could then be no longer accurately determined by the height of the water above. The pressure gauges usually indicated a pressure of one or two pounds more than the depth of water would give by calculation. This was caused in a great measure, however, by the friction of the air in the pipes, the gauges being at the pumps and not in the air chamber. A column of water one hundred and ten feet six inches in height would be equal to a pressure of 47.96 pounds per square inch, assuming the weight of the water to be 62.5 pounds per cubic foot. The greatest pressure marked by the gauges was fifty-two pounds, and it is not probable that the pressure in the air chamber ever exceeded fifty or fifty-one pounds.

EFFECTS OF COMPRESSED AIR ON THE MEN.

The first symptom manifesting itself, caused by the pressure of the air, is painfulness in one or both ears. The Eustachian tubes extending from the back of the mouth to the bony cavities over which the drums of the ears are distended, are so minute as not to allow the compressed air to pass rapidly through them to these cavities, and when the pressure is increased rapidly, the external pressure on the drums causes pain. These tubes constitute a provision of nature to relieve the ears of such barometric changes as occur in the atmos-

phere in which we live. The act of swallowing facilitates the passage of the air through them and thus equalizes the pressure on both sides of the drums, and prevents the pain. The pressure may be admitted into the air-lock so rapidly that this natural remedy will not in all cases relieve it. By closing the nostrils between the thumb and fingers, shutting the lips tightly and inflating the cheeks, the Eustachian tubes are opened and the pressure on the inner and outer surfaces of the tympanum is equalized, and the pain prevented. This method must be used and repeated from time to time as the pressure is let on, if it be increased rapidly. No inconvenience is felt by the reaction when the pressure is let off, as the compressed air within the drums has a tendency to open the tubes, and thus facilitates its escape through them; whereas increasing the pressure has the effect of collapsing them and therefore makes it more difficult to admit the compressed air within the cavities of the ears. It frequently occurs, however, from some abnormal condition of these tubes, as when inflamed by a cold in the head, that neither of these remedies will relieve the pain. To continue the admission of compressed air into the lock, under such circumstances, would intensify the suffering, and possibly rupture the tympanum, therefore the lock tenders were particularly instructed to shut off the compressed air at the moment any one in the lock experienced pain about the ears; and then, if it could not be relieved by the above means, the lock was opened and the person was not permitted to go through into the air chamber. Sometimes fifteen minutes were occupied in passing persons through the first time, after which they usually had no further trouble from this cause.

The fact that the depth penetrated by the air chamber was considerably greater than that hitherto reached in any similar work, left me without any benefit from the experience of others, in either guarding against any injurious effects of this great pressure upon the workmen and engineers subjected to it, or of availing myself of any known specific for relieving those affected by it. When the depth of sixty feet had been attained, some few of the workmen were affected by a muscular paralysis of the lower limbs. This was rarely accompanied with pain, and usually passed off in the course of a day or two. As the penetration of the pier progressed, the paralysis became more difficult to subdue. In some cases the arms were involved, and in a few cases the sphincter muscles and bowels. The patients also suffered much pain in the joints when the symptoms were severe. An average of at least nine out of ten of those affected suffered no pain whatever, but soon recovered and generally returned to the work.

The duration of the watches in the air chamber was gradually shortened from four hours to three, and then to two, and finally to one hour.

The use of galvanic bands or armor seemed, in the opinion of the

Superintendent of Construction, the foremen of the chamber, and the men, to give remarkable immunity from these attacks. They were all ultimately provided with them. These bands were made of alternate scales of zinc and silver, and were worn around the wrists, arms, ankles and waist, and also under the soles of the feet. Sufficient moisture and acidity were supplied by the perspiration to establish galvanic action in the armor, and as the opinion among those most accustomed to the chamber was almost unanimous in favor of this remedy, I am very much inclined to believe it valuable.

Immediately on the manifestation of greater severity in the symptoms, a hospital boat was fitted up at the pier, and one of the ablest physicians in the city (Dr. A. Jaminet) was engaged to attend those affected, and also to institute such sanitary measures as his judgment should dictate. A careful examination of the health and bodily condition of every workman was daily made, and none were permitted to engage in the work without the approval of Dr. Jaminet. Those most severely affected were sent to the City Hospital and had the benefit of the advice and treatment of its resident physician, Prof. E. A. Clark. The total number of men employed in the air chamber of this pier was three hundred and fifty-two. Of this number about thirty were seriously affected. Notwithstanding the care and skill with which those most severely attacked were treated, twelve of the cases proved fatal. Each one of these, without exception, I believe, was made the subject of careful inquest by the coroner, aided by an autopsy conducted usually by some of our most skillful surgeons and physicians. Whilst the exciting cause in all of these cases was doubtless the exposure of the system to the pressure of the condensed air of the chamber, the habits and condition of several of those who died were, at the time they went to work, such as would have excluded them from it if subjected to the examination of Dr. Jaminet, and the verdict in about one-half of the cases gave a totally different cause for the death of the patient. Nearly or quite all of these deaths happened to men unaccustomed to the work; several of them to men who had worked but one watch of two hours. In contrast to this, is the fact that quite a large number of the men (certainly one-half of those constantly employed) commenced with the work at its inception and remained throughout its continuance entirely without injury or inconvenience.

The gentlemen composing the engineer corps of the bridge all visited the air chamber, some of them quite often, either in the discharge of their professional duties, or from motives of curiosity, and none of them suffered any injury whatever.

Much diversity of opinion was expressed by the medical gentlemen who investigated the symptoms and held autopsies of the deceased. Some of these gentlemen maintained that a slower transition from the abnormal to the natural pressure would have been less injurious;

others claimed, on the contrary, that it was from the too rapid application of pressure in passing from the natural into the compressed air. The fact that the air-lock tenders were in no case affected, although subjected many times during a watch of two hours in the air-lock to rapidly alternating conditions of the atmosphere, at one moment in its normal state in the lock, and five minutes later exerting a pressure of fifty pounds per square inch upon every part of the body, would seem to prove both of these theories unsound, and lead us to believe that in the length of time to which the human system is subjected to this extraordinary pressure, exists the real source of danger, and not from any rapid alternations of pressure to which it is exposed. After the caisson reached the rock, I have frequently, when passing through the air-lock, admitted the compressed air into it so quickly that none but those well accustomed to it could relieve the pressure upon their ears, and yet I felt no ill effects whatever from this rapidly increased pressure; and in going out I have let the pressure off so fast that the temperature in the lock has fallen thirty-two degrees (Fahrenheit) in consequence. These transitions occupied but three or four minutes.

The fact that the air chamber was briefly visited by thousands of persons, including many delicate ladies, even after it had reached the bed-rock, some remaining as long as an hour in it without any of them experiencing the slightest ill effects from the pressure, and the fact that no cases of any importance whatever occurred among the workmen after the watches were reduced to one hour, satisfies me that this is the true cause of the paralysis, and that by lessening still more the duration of the watches, a depth considerably greater can be reached without injury to the workmen. Too long a continuance in the air chamber was almost invariably followed by symptoms of exhaustion and paralysis. Dr. Jaminet, on one occasion, remained in two and three-quarter hours, when the depth was over ninety feet, and was dangerously attacked soon after reaching home.

Symptoms of paralysis rarely occurred in the shaft, but generally after the stairs were ascended, and never in the air lock or air chamber.

A large amount of money has been gratuitously expended by the Company in assisting and providing for those who were seriously affected, and in relieving the wants of their families during their illness.

As a merited recognition of the courage, fidelity and services of the men employed in the air chamber of the east pier, and as an evidence of my personal appreciation of their faithfulness and good conduct, I have placed in the appendix to this report the names of those engaged in the work when the pier reached the rock.

THE WEST PIER.

The sinking of the west pier began on the 15th day of January of last year, that being the day on which the first stone was laid on the caisson. As it was commenced twelve weeks later than the east pier, advantage could be taken of the experience gained in sinking the latter. On the east pier the interruption and annoyance caused by the necessity of riveting on the iron plates outside of the masonry to exclude the water, as the pier descended, led me to devise some means whereby this inconvenience might be prevented and the cost of the iron saved. The design of the west caisson was so modified that the use of these plates could be abandoned after the first twenty-nine feet; nine feet of this height being the air chamber, and the remaining twenty feet enveloping the masonry above the chamber. This height of plate iron was deemed requisite to give such rigidity to the caisson as would insure it against any twisting or straining that would endanger the bond of the masonry. After a depth of forty or fifty feet was reached by the east pier, it was found evident that brick linings in the shafts, although surrounded by many feet of masonry carefully laid in hydraulic cement, were not sufficient to exclude the water, which at this depth filtered through quite rapidly. To prevent this and enable the iron around the outside of the pier to be dispensed with on the west pier, its shafts were lined with white pine staves three inches thick in the centre shaft, which was ten feet in diameter, and two and a half inches thick in the smaller wells, which were four feet nine inches in diameter. This device answered admirably, and the estimated saving in plate iron over the original design was about $10,000. The lower staves were, however, found to be too weak to sustain the high water of the spring freshet without expansion bands of 1x3-inch bar iron, which were placed against them in the shafts in time to avoid any disaster. This novel feature of wooden linings and no exterior envelope for the masonry will be introduced in the east abutment. The caisson for it is, however, made so strongly that the iron will only be brought up to a height of twelve feet around the base of the masonry. The lining staves in its wells will be so much stronger that they will require no internal supporting rings of iron.

Nothing could have exceeded the perfect working of these economic improvements in sinking the west pier, had not the contractors failed to deliver the granite for it in time. When the point was reached at which the granite became necessary, the surface of the masonry was six or eight feet above water and the base of the pier eighteen or twenty feet from the rock. A judicious view of the case, having reference solely to the cost of constructing this pier, would have dictated a suspension of the work until the stone should have arrived, rather

than continue the sinking of the pier and suffer the top of the masonry to descend below the surface of the water. Other questions, however, were involved, of a more serious nature. It was universally conceded that any effort to negotiate the securities of the Company would be fruitless, unless preceded by an absolute demonstration of the practicability of putting down the channel piers of your Bridge upon the bed-rock of the Mississippi, through the unusual depths of water and sand that were to be encountered. The east pier was in a similar condition at this time, and there remained no alternative but to continue sinking both, to do which it was necessary to build up and brace out the iron plates which had been carried up from the air chamber around the masonry of the east pier, and thus dam out the water from covering the top of the masonry as it descended below the surface of the Mississippi, so as to be able to resume the laying of stone when the granite should arrive; and as the west pier was without any such iron envelope, it became necessary to attach the wooden walls of a coffer-dam to its sides in such a manner as to exclude the water from the top of the pier. This was done by padding the lower edge of the dam and attaching its sides securely to the masonry, several courses below the top. This answered very well until the last nine inches of this pier was sunk to the rock. Some of the bolts holding down the dam at the south end of the pier gave way, and the friction of the sand, then fourteen feet high on the outside of the dam and nearly to the surface of the water, prevented the settlement of the dam with the pier at this particular point. Two outside courses of the limestone to which it was attached were held up by the dam nearly across the entire end of the pier. This mishap made it necessary to pump away the sand outside this end of the dam, and put down a large pad, or wooden covering, reaching below the two disturbed courses, then pump out the dam and relay them. This was done at a depth of about seventeen feet below the surface. The dam was not pumped out till the granite arrived, as the water over the pier did not prevent the work in the chamber, access to it being obtained through the wooden shafts or wells which passed down through the water that was over the masonry. This unexpected trouble, and that at the east pier, were caused solely by the failure of the Richmond Granite Company to deliver the granite in time. Its delivery was due several months before it was needed, and yet it was not delivered until several months after it was wanted. The loss to your Company resulting from this failure I estimate to amount to at least $50,000.

THE EAST ABUTMENT PIER.

The complete success which attended the sinking of the east pier convinced me of the practicability of sinking the east abutment pier

to the rock in the same manner. The original plans of the Bridge did not contemplate resting this abutment on the rock. It was believed quite practicable to protect its foundation with rip-rap stone, and to secure stability and safety by resting it on piles, which were to have been driven to a distance of fifty feet below low-water mark. When the Directory of the Company were assured of the practicability of resting this abutment upon the bed-rock itself, and of thus terminating forever all doubts as to the absolute stability of each one of the four great piers of your Bridge, the desire that this, the largest of them all, should be placed on the rock also, was unanimous; although the excess in cost involved over that of the original design was understood to be about $175,000. No less than ten thousand additional cubic yards of masonry *below* the line of the tops of the piling on which it was originally intended to start the masonry, are required to sink the pier to the rock. Consequently, below this line it will require nearly as much masonry as will be contained in the west abutment when the latter is completed.

This abutment, when completed, will contain twenty-two thousand four hundred and fifty-three cubic yards of masonry, including concrete and brick work, and will measure in height, from the rock to the top of its cornice, one hundred and ninety-six feet nine inches.

The depth of the rock at the site of the abutment was ascertained by careful borings to be eight feet lower than that at the east pier, or one hundred and thirty-six feet below high-water mark.

It is not probable that we shall have to contend with much deeper water or much greater air pressure than that encountered in sinking the east pier The bed-rock at this abutment is ninety-four feet below extreme low-water mark, and the river is not likely to be more than eighteen feet above that during the seasons occupied in sinking the pier. Extreme low-water mark is only reached when the river is gorged with ice above the city, and the volume of water below the gorge becomes in consequence greatly lessened. The ordinary low water rarely reaches a point within five feet of low-water mark.

In accordance with the wish of the Directory, preparations for sinking this abutment to the rock were commenced and are now nearly completed. The caisson is nearly ready for launching, after which it will be immediately towed into position and be made ready for sinking. It will cover, when on the rock, five thousand square feet of surface, and is therefore about one-quarter larger than the base of the east pier. A large trestlework has been erected immediately east of the site of this abutment, extending a few feet above high-water mark, on which is being placed a portion of the necessary machinery for sinking the caisson. This trestlework was rendered necessary because of the shallowness of the water on that side of the abutment. On the west side of the caisson one of the derrick boats used at the east pier will be located, and on the trestlework will be placed much

of the machinery of the other derrick boat, which was used on the other side of the east pier.

THE EAST ABUTMENT CAISSON.

This caisson will have several novel features in its construction, which I think will make it superior to those used for the east and west piers. The main shaft will have at the bottom two air locks, each eight feet in diameter, instead of one of but six feet. The main shaft will be carried down into the air chamber ten feet in diameter, instead of but five feet.

The east pier caisson had six other shafts of four feet nine inches in diameter, with air locks of the same diameter at the bottom of each. This caisson will have but two other shafts of four feet in diameter, with an air lock at the bottom of each, eight feet in diameter. These last two shafts are enlarged below the roof of the air chamber to eight feet in diameter each. The increased diameter of the locks will contribute to the health of the men, as it is sometimes necessary for twelve or fourteen of them to be in one of them at the same time, for several minutes, until the pressures are equalized. As all four of these locks are within the air chamber, and also the lower ends of the three shafts, and as about one thousand eight hundred cubic feet of space is occupied by them, there will be that much less space to fill in the compressed air when the pier is down.

The centre shaft alone will be used for the workmen, unless some unforeseen accident should render it necessary for them to use one or the other of the side shafts, which are provided almost solely for safety. The extra size of the locks makes either one of them capable of holding, in an emergency, all the men that will be in the air chamber at one time, and hence their security will be increased.

To avoid the labor of walking up a circular stairway about one hundred and twenty feet high after leaving the air chamber, the main shaft, in addition to the stairway, will have an elevator or lift to bring the men up. This, it is believed, will contribute greatly to their health. When they are at work in a pressure of forty-five or fifty pounds above that of the natural atmosphere, there ensues a rapid exhaustion of the physical energies. When relieved from duty, a considerable degree of prostration is frequently manifested, and the foremen of the different gangs were in consequence instructed by the physician to cause the men to ascend the stairs leisurely, to avoid increasing it. I confidently believe, therefore, that by bringing the men to the surface in the elevator, there will be much less danger of injury occurring from their employment in the air chamber.

LIGHTING THE CAISSON.

A different method of lighting the air chamber will likewise be adopted. In the other caissons much inconvenience was experienced

on account of the particles of unburned carbon thrown off from the flames of the candles used. The consumption of the candles under the action of the compressed air was much more rapid than in the normal atmosphere. At the depth of one hundred feet they were found to be consumed in about three-fifths of the time required in the open air. Large quantities of smoke were emitted from the flames, and the air was filled with particles of floating carbon, which could only be removed thoroughly by placing a rose jet on the nozzle of a water hose in the chamber, and discharging the spray in every direction. Some amelioration of the evil was obtained by burning the candles under an inverted funnel, or chimney, communicating with one of the shafts by a small outlet pipe, through which the escape of the compressed air was regulated by a cock, thus creating a draft above the flame by which the smoke was carried off.

The calcium light would probably prove the most satisfactory one which could be employed in the chamber, were it not for the excessive cost of it in this city. For the one hundred and fifty days which will be required in sinking this pier and completing its foundation on the rock, the cost of lighting the three compartments of the chamber with calcium lights would be at least $5,000. By the means devised for the purpose the cost cannot exceed one-fifth of that sum.

The difficulty of extinguishing a flame in an atmosphere of such density caused me to forbid the use of oil lamps in the chamber before a depth of eighty feet had been reached. The clothing of two of the men having taken fire from contact with some of the hand lamps or candles used in the caisson, it was found exceedingly difficult to extinguish the flames. One of them was severely burned, although his garments were almost entirely woolen. It was deemed unsafe to risk the danger of having the clothing of the men saturated with oil from the accidental breaking of a lamp, which might, by the same casualty, ignite their garments and thus endanger their lives. The use of oil was therefore forbidden.

At the depth of eighty feet it was found that the flame of a candle would immediately return to the wick after being blown out with the breath. At the depth of one hundred and eight and one-half feet below the surface of the river, I blew out the flame of one of them thirteen consecutive times in the course of half a minute, and each time, excepting the last, it returned to its wick. Almost as long as a small portion of the wick remained incandescent, the flame would return, and when the glowing particle of two separate candles failed to possess sufficient heat to restore the flame to either, it would reappear at once by placing the luminous portions of the two wicks in contact.

The chamber of this caisson will be lighted by candles contained within glass globes of similar construction to those used in lighting railway carriages. The glass will be of strength sufficient to sustain the external pressure of the condensed air. The chimney will consist

of an outlet pipe of one inch diameter, communicating with one of the shafts, and the compressed air will only be admitted within the globe in which the candle is placed, through a small regulating valve. The candle will therefore be burning under the normal pressure of air. A stop-cock in the chimney will prevent the escape of air from the chamber through the globe, when it is desirable to put in another candle, or to clean the glass,

TIMBER WORK.

Beneath the masonry piers of suspension and truss bridges it is quite common to employ a considerable amount of timber. Where the pressure upon the pier is a vertical one, this economical substitute for stone is admissable, but in the piers of an arched bridge, where some one span is at times loaded while the others are unloaded, the thrust of the loaded arch has a tendency to oscillate the piers, and with a few feet in thickness of a material so elastic as wood under their bases, this oscillation would prove a dangerous feature. In the abutment piers where the thrust is only from one side, and oscillation is prevented by the works on shore, timber may be safely used to a considerable extent. To give the desired stiffness to the caisson for this abutment and avoid the more costly use of iron, the roof of the air chamber is made of timber four feet and ten inches in thickness. A large amount of timber is also used in constructing and stiffening the sides of the air chamber, which are ten feet high, and in forming two horizontal trusses or girders through the air chamber. These two girders are each ten feet thick at the top, three and one-half feet at the base, and nine feet in height. They are about seventy-three feet long, and are interlocked at each end with the sides of the air chamber. They divide this chamber into three nearly equal compartments in the direction of the length of the Bridge. Communication is made between these compartments by means of two openings through each girder.

The sides of the chamber are eight and one-half feet thick at the top and eighteen inches at the bottom, and are composed of timbers, some placed vertically, others horizontally, snd some inclined at an angle of about forty-five degrees, and the whole, including roof and girders, thoroughly interlocked together and bolted with large iron bolts. All of the timber is of the very best white oak, and was squared up with two steam planers belonging to the Company. In addition to the iron bolting used, these timbers are thoroughly secured together with large white oak tree-nails.

The wood work of the caisson has been most admirably executed under the superintendence of Mr. John Dunlap, master of ship carpenters.

PLATE IRON WORK.

Enveloping this entire wooden structure is an iron covering riveted together to prevent the escape of the air which is to supply the workmen. This is of three-eighth inch plate iron, and its sides are increased in thickness at the bottom edge to three inches, by riveting four three-quarter inch plates together. These extend several feet up the sides. This iron edge extends ten inches down below the wooden sides and forms the cutting edge of the caisson. Every two feet the iron sides are strengthened by vertical angle irons three by seven inches in size, riveted on flat wise on the outside of the caisson. Through these angle bars, bolts one and a half inches in diameter are inserted, and by them the iron and wooden sides are strongly held together. This iron covering extends over the wooden top of the air chamber and forms a floor on which the masonry will be laid. The three shafts passing through the floor, by which access to the chamber is obtained, are tightly riveted to it.

The iron sides are carried up twelve feet above this floor, where they will terminate. The masonry above this point will therefore have no exterior envelope such as the east pier had.

Nearly all of the iron used in this envelope was obtained from the hull of the iron gun-boat Milwaukie, the wreck of which was purchased about eighteen months ago. This iron work has been executed by Capt. Wm. S. Nelson, the skillful and energetic contractor who built the caissons of the two channel piers.

WATER TIGHT LININGS.

The water penetrating the masonry will be excluded from the three shafts by white pine linings, arranged like the staves of a cask. The staves composing this lining in the main well or shaft, which is ten feet in diameter, will be ten inches thick in the lower part, and will be gradually diminished to three inches at the top. In sinking the pier, the top of the masonry and shafts will be kept constantly built up above the surface of the river.

FILLING THE AIR CHAMBER.

The most valuable improvement in the design of the caisson will I think, be found in the method devised for filling the chamber when it has reached the rock. It is a well established fact that sand constitutes one of the most reliable and durable materials for foundations known, if availed of in positions where it can be securely retained under the structure erected upon it. It is an equally well

established fact that timber, when entirely submerged in fresh water foundations, is indestructible. These two facts will be relied upon in filling the air chamber and fixing the foundation of this pier upon the rock. Instead of concrete, sand will be chiefly used for filling the chamber. The sides of the caisson are of great thickness, and are thoroughly interlocked at the corners of the air chamber, and at the ends of the girders. The possibility of the sand surrounding the pier ever being scoured out to the rock, at the site of this abutment, is a very remote one. It is certainly much more improbable than that it may be scoured thus deeply at the sites of the two channel piers. To avoid all danger from this very remote possibility throughout all time, whatever space there may be existing between the timber walls of the caisson and the bed-rock, after the caisson shall have reached it, will be thoroughly concreted, so that these walls will have a substantial bearing upon a solid material which cannot be affected by any current that may possibly wash the base of the pier. The walls of the air chamber are so framed as to be sufficiently strong to resist the bursting pressure of the sand within the chamber, caused by the weight of the masonry of the pier and half the side span upon it, even after all the iron used in it shall have been corroded away. The base of the pier is 5,000 square feet in area, and the weight of the entire pier, including one-half of the span, will be about 46,500 tons. The pressure per square foot on the rock would, therefore, be 18,600 pounds. The area of the wooden edge of the caisson, including that of the bottom of the girders, air-locks and shafts, is about 1,250 square feet. This area alone would be capable of sustaining the pier, without any additional support from the sand contained within the air chamber. Without this sand filling, the pressure upon the wooden base of the caisson (including the locks and shafts) would be about 74,000 pounds per square foot, or 514 pounds per square inch. This pressure is not beyond the power of good white oak to resist, nor would it be sufficient to crush the concrete that will be used in filling the small space between the oak and the rock.

Tests made with our testing machine upon a number of blocks of concrete only six weeks old, gave an average resistance to crushing equal to one thousand two hundred pounds per square inch. Of course, with the integrity of the exterior of the caisson unimpaired, the escape of sand from the interior would be impossible. With the interior compactly filled, the pressure of the superincumbent mass must necessarily be very nearly equally distributed over every part of the caisson, and hence it cannot exceed about 16,000 pounds per square foot.

The tedious process used in concreting the air chamber of the channel piers, together with the objections to working men at such great depths, induced me to devise some method by which a smaller amount of manual labor could be made to accomplish equally good results.

By the plan determined on in this case, I confidently hope to accomplish the necessary work in the air chamber with a fifth or sixth of the manual labor which was required under the east pier.

This method is so simple as to be readily explained. So soon as the rock shall have been struck by the iron edge of the caisson the space then remaining between the wooden walls of the caisson and the rock, will be thoroughly concreted. The sand under the two girders will be left intact. The borings indicate that the rock is quite level, and it is not probable that inequalities of more than eighteen inches will be found in it. It is estimated that one hundred cubic yards of concrete will be sufficient to support these walls, forming a bed of an average width of three feet six inches by two feet six inches in height. This concreting being done, all of the pipes passing vertically through various parts of the pier, and used for air, water and sand-pumps, will be closed at the top, and the pumps, valves and pipes connected with them in the air chamber will then be taken off. There will be nineteen of these vertical pipes, each either four or six inches in diameter, the lower ends of which will be enlarged conically through five feet of their lengths. These pipes being opened at their lower extremities, and one of the inner doors of an air-lock being secured from being clogged by sand, the air from the chamber will be permitted to escape, and the chamber will be filled with water. This being done, sand will be introduced through the various vertical pipes mentioned. By means of plummets in these pipes, we shall be able to determine the height of the sand discharged in them, and when it is near the roof of the chamber the air will be again pumped in, and workmen will be sent in to level it off. By repeating this process two or three times, the chamber can be filled nearly to the roof with sand compacted in the water, which will insure its solidity. The remaining space can then be filled with concrete rammed in under the roof of the chamber. The great thickness of the walls and of the girders where they join the roof reduces the area of the upper part of the chamber very greatly. The upper three feet of it measures only two thousand and twenty-five cubic feet in area exclusive of the air-locks and shafts.

To fill the air chamber of the east pier required one thousand three hundred and forty cubic yards of concrete which was placed in position by manual labor, under an air pressure of nearly fifty pounds per square inch. This pier is twenty-five per cent. larger, and will require only about two hundred cubic yards of concrete to be placed in it under similar conditions; hence the work required to be done in this chamber will be greatly less than in that of the east pier.

WEST APPROACH.

In this approach, which will be entirely of stone, there will be five arches of twenty-six feet eleven inches span, and forty-two feet ten

inches in height above the level of the street. The foundations for the piers to support these arches, all rest upon the rock underlying the wharf. These foundations are nine feet by forty-six feet six inches. The one next to the west abutment is the deepest of the five, the rock being forty-one feet eight inches below the City Directrix. This foundation is already completed and will soon receive the Missouri rock-faced red granite, which will form the base for the fine cut sand stone, of which the approaches, on each side of the river, will be built. The foundation for the second pier of this approach has just been commenced. The foundation for the third and fourth piers are completed and are ready for the sand stone. The masonry already laid in these three approach piers measures nine hundred cubic yards.

The foundation for the fifth pier will be in the line of the houses fronting the wharf, and has not yet been commenced. The cellars of the houses, where it is to stand, have been blasted out of the solid rock, and this pier will be rapidly and easily constructed when commenced.

THE EAST APPROACH.

The piers for this approach will be built upon pile foundations, none of which have yet been commenced.

There will be no difficulty in completing this approach within the desired time, and it will be more convenient and economical to begin it after the work on the west approach is more advanced. In design it is almost exactly like the west one.

SAND STONE.

In the selection of sand stone, the greatest possible care has been exercised. This selection was more especially supervised by Col. W. Milnor Roberts, Associate Chief Engineer, who personally visited and carefully inspected every sand stone quarry of any note within available distance of the work. The one selected lies close to the Mississippi River, near St. Genevieve, and is distant about sixty-five miles from St. Louis. The stone is a pure sand stone, of a warm, yellowish tint. It is of uniform color, free from blemishes, and from the tests made of it, promises great durability.

A force has been at work for some time getting out and cutting the stone, and no fear of delay is entertained on account of non-delivery of it in time.

GRANITE.

Col. Roberts has also devoted much of his time to the selection of the granite used, and to be used in the construction of your Bridge.

Several examinations were made by him of the Eastern granites, and almost every quarry, from Richmond to Buck's Harbor, in Maine, was visited by him with a view to obtaining the best and cheapest that could be had. A contract for the first seven hundred cubic yards was made by him with the Richmond Granite Company for gray granite. Subsequently another was made with Messrs. Thomas Westcot & Son, of Maine, for all the gray granite that will be required for the two abutments and the two channel piers. All four of these piers will be faced with granite ashlar above extreme low water mark, except those parts of their sides which are above the springing of the arches and beneath the roadway, and inclosed between the spandrels of the arches. This portion, which is much less exposed to the weather and to view, will be of cut sand stone.

Missouri red granite will also be used as ashlar, but only in the bases of the approaches and on the T walls of the abutments, and will appear only to the height of the curb stone on the St. Louis wharf, which is nearly the level of the City Directrix. For this purpose about fourteen hundred cubic yards will be required. This granite promises to be equally as durable as the gray, and that which is already laid up in the work is greatly admired on account of the richness and beauty of its color.

It is to be regretted that proof could not have been given, at an earlier date, of the capacity of a Missouri quarry to supply a material so excellent and desirable. One of the good results of your enterprise is the discovery and development of this extensive quarry, owned by Hon. B. Gratz Brown, with whom a contract was made last April for fourteen hundred cubic yards of the stone, a great part of which has been already delivered. This quarry is distant ninety miles from St. Louis, and three miles from the Iron Mountain Railroad.

Several hundred dollars were expended by the Bridge Company in fruitless endeavors to obtain the proper quality of gray granite from a quarry in this State prior to this contract, and this discouragement, together with the unfavorable results of examinations made of other unproved quarries in this State, created a reasonable assurance that no suitable granite would be discovered in Missouri in time for our wants. Hence, no alternative remained but to seek for it elsewhere.

TESTS OF GRANITE.

In the Appendix will be found two interesting reports, one from Prof. Felix McArdle and the other from Dr. Eno Sander, chemists of high standing in St. Louis, giving the chemical tests applied by them, and the results produced by these tests upon the samples of red granite now being used in the construction of your Bridge.

The very careful experiments and report of Prof. McArdle were made gratuitously.

A resolution, thanking him for this generous manifestation of his interest in your enterprise, was passed by the Board of Directors of your Bridge Company.

MAGNESIAN LIMESTONE.

The interior of all the masonry will be of magnesian limestone, from the Grafton quarries. None of this stone will be exposed to the weather. It is remarkably strong. Many tests of its compressive strength have been made in the Company's testing machine, where its resistance has, in several instances, exceeded 17,000 pounds per square inch, which is equal to that of granite.

A curious fact has been developed by these tests, which is that the modulus of elasticity of this stoue is about the same as that of wrought iron. That is, a given weight placed upon a wrought iron column and on a column of the Grafton stone of the same size, will produce an equal shortening in both ; while the elastic limit (or breaking point) of the stone is not far below the limit at which the wrought iron would be permanently shortened. A column of the stone two inches in diameter and eight inches long, was shortened under compression in the testing machine nearly one-quarter of an inch without fracturing it. When the strain was removed the piece recovered its original length.

TESTING MACHINE.

The testing machine, the design of which was made by Col. Henry Flad, Chief Assistant Engineer, has been in operation for several months, and has given the greatest satisfaction. By means of a very simple little instrument, suggested by Chancellor Chauvenet, and matured by Col. Flad, the most delicate changes in the length of the specimen can be accurately recorded, with a degree of minuteness never before obtained or even approximated in any testing machine, so far as my information extends. By this instrument it is perfectly easy to detect a change in the length of the piece equal to the two hundred thousandth part of an inch.

A brass collar is slipped over each end of the specimen, and these are secured by three pointed set screws in each collar. Any shortening or lengthening of the piece will, of course, alter the distance between the two collars. One collar has on the side of it a small flat surface, or vertical table. Against this table is placed a little vertical steel cylinder, which is held against the table by the end of a little flat horizontal bar that is secured at its other end to the other collar. This bar is held against the steel cylinder by a spring, having suffi-

cient strength to keep the cylinder from falling. It is evident now that if one collar be brought nearer, or is moved further away from the other, the steel cylinder will be rotated, as one side of the cylinder is pressed against the table, which is attached to one collar, while the other side is pressed by the little bar that is fastened to the other collar. If the specimen be subjected to pressure it will be shortened and the collars will approach each other. If tension be applied to the specimen, the piece will be stretched according to its intensity. and in either case the rotation of the little steel cylinder will indicate the measure of the disturbance that has occurred between the two collars, and it will give it absolutely without any element of error entering into it from any change of the dimensions of parts of the machine under strain. By placing on the top of this little cylinder a small vertical mirror, the extent to which the cylinder has been rotated may be determined in the following manner: Twenty-five feet from the mirror an arc of a circle is struck, the little steel cylinder being the centre of the arc. On this arc is erected a scale of inches, with decimal subdivisions. This scale being illuminated by gaslight, can be easily read in the mirror by means of a small telescope placed immediately above the scale. The angles of incidence and reflection at the surface of the mirror being equal, it follows that one-fourth of a cómplete rotation of the mirror would be equal to a half circuit of the circle of which the arc is a part; or, in other words, a movement of the mirror of but one degree would be shown on the scale, by the reading of a space equal to two degrees, or the one-hundredth part of an inch on the scale, would really be only half so much, or the two hundredth part of an inch, when seen in the mirror. The diameter of the little cylinder is so proportioned to the radius of the arc as to make the smallest subdivision of the scale equal to the twenty thousandth part of an inch, but the observer, after a little practice, can subdivide these divisions, which are magnified by the telescope, so as to observe the two hundred thousandth part of an inch.

The power is applied to the specimen under trial by means of a hydraulic press, the ram of which moves horizontally. The ram has a steel rod extension passing through the rear end of the cylinder. Specimens for testing by tension have one of their ends secured to this steel rod, and the other to the end of a scale beam. Specimens for crushing are placed at the other end of the cylinder and are compressed between the end of the ram and a crosshead. This crosshead is attached to the end of the scale beam before mentioned, by four powerful rods of steel surrounding the cylinder and leading back to a crosshead attached to the beam. This latter crosshead is detached from the beam when tensile experiments are being made.

It will be obvious, on reflection, that when a piece is being crushed by the thrust of the ram, the four bolts sustaining the crosshead

against this thrust must stretch in proportion to the power applied, and hence the specimen will be moved bodily in the same direction, and that this will affect the accuracy of the readings of the mirror, as it too will be moved horizontally with the specimen to which it is attached. To correct this minute error in the readings, a second mirror and scale are used to ascertain the extent of this horizontal movement. The table holding this second mirror, against which the little cylinder rotates, is secured to the frame of the testing machine, which has no strain on it, and the little bar for rotating the cylinder is attached to the crosshead; of course, any movement of this head causes a rotation of this second mirror by which the extent of the movement can be at once ascertained.

It is equally important to know the exact weight applied to the specimen as well as the change of form assumed by it when subjected to the weight. Having no faith in the accuracy and durability of the ordinary mercury and spring gauges for such high pressures as are required in a hydrostatic testing machine, I determined that the absolute strain on the piece must be weighed on the balance. This, Col. Flad has very ingeniously accomplished by a system of levers, balanced on hardened chrome steel knife edges and boxings, sufficiently powerful to stand a strain of one hundred tons, and yet so delicate as to be turned by the weight of one-half of an ordinary cedar covered drawing pencil when placed in the balance. One pound weight placed in the balance, equals a ton of two thousand pounds weight on the specimen.

I feel safe in asserting that the company have a testing machine which can scarcely be excelled in the accuracy, delicacy and minuteness of its results.

It has been placed in charge of Mr. Paul Dahlgren, C. E., by whom a carefully tabulated record is kept of all tests made with it. A great variety of these have already been made upon specimens of steel, iron, woods of various kinds, granite, brick, limestone, concrete, cement, models of tubes, trusses, etc., etc. Much valuable information having direct reference to the work in hand, has been already obtained by these experiments.

SUPERSTRUCTURE.

On twenty-sixth day of February last, a contract was made with the Keystone Bridge Company, of Pittsburg, for the construction and erection of the superstructure of your Bridge, including that of the approaches. By this contract the Keystone Bridge Company undertakes to furnish all materials at the same prices per pound and per foot, at which they were estimated in my published report of May, 1868, excepting cast steel work, which is to be furnished at $20.00 per

ton less than the cost set forth in that report. There will be about two thousand five hundred tons of steel used, therefore the saving on this item will amount to about $50,000. The contracting party will, however, receive $40,000 more for erecting the three spans than the estimate in the report. Every other item of cost as set forth in the report referred to, is the price per pound or foot to be paid the Keystone Bridge Company. The amounts set forth under the head of engineering and contingencies, in that report, and aggregating $149,-512.14, for superstructure of Bridge and approaches, are reserved by your company, and will be ample to cover any excess of materials required over the amounts estimated, and for engineering expenses, etc.

By the terms of the contract with the Keystone Bridge Company, it agrees, under a severe forfeiture in case of failure, to complete the structure, ready for use in all its parts, in seventeen months from the time working drawings were furnished to it: provided it is not delayed by masonry work after the first of March next. In case of such delay, the time of completion is to be extended no longer than the time it is so delayed. Completed working drawings were not furnished until the first of July, as the completion of certain parts of them was dependent upon data that were obtained from the testing machine, and which could not be ascertained at an earlier period. This delivery of drawings fixes the time for completion of the Bridge on the first of December of next year. I have no apprehensions that the masonry will not be completed in season to prevent any claim for an extension of time on the part of the Keystone Bridge Company.

I have been informed that the Keystone Bridge Company has contracted with the Wm. Butcher Steel Works Company, of Philadelphia, to furnish the cast steel that will be required in the work.

Specifications for the cast steel work will be found in the Appendix to this report.

I have tested so many samples of steel made by this company which surpassed in strength the requirements set forth in these specifications, that I have no fear of its not being able to supply the quality required. Several pieces of this steel have shown limits of elastic reaction ranging from seventy thousand to ninety-three thousand pounds per square inch.

Since my report, 1st May, 1868, in which the plan of superstructure was described, I have made several modifications in the general arrangement of the arches and in the details of their construction, which will considerably improve the architectural appearance of the Bridge and simplify its fabrication.

These changes consist mainly in using but one cast steel tube of eighteen inches diameter, instead of two of nine inches, in forming the upper and lower members of each one of the four ribbed arches composing each span; and in increasing the depth of each one of the

arches from eight feet to twelve feet from centre to centre of these tubes.

The railways (which are below the roadway) are raised four feet, so that in no place will they appear below the arches, as they did in the original design. In that design the railways were eight feet lower than the centre of the middle span. By deepening the arch four feet and raising the tracks four feet, they are brought level with the centre of this span, or above the soffit of the arch. The lower ribs or tubes of the arches spring from the piers at their original level, consequently the arch has four feet less versed sine or rise than before. To lessen the grade of the railways it was necessary that the tracks should descend each way from the centre of the middle span. This would cause them to fall below the centres of the side spans, to avoid which the level of the springing of these two spans has been lowered eighteen inches at each abutment. That is the ends of the arches of the side spans resting against the abutment piers, will be eighteen inches lower than the other ends which rest against the channel piers. These arches, like the central ones, have four feet less rise than as originally designed, and by lowering their shore ends, as stated, an additional gain of nine inches depression is obtained at their centres, by which the gradients of the tracks are proportionately lessened towards the ends of the Bridge.

Raising the tracks to the height of the centres of the arches will unquestionably improve the appearance of the structure, and it is generally conceded that the alteration in the level of the springing of the shore ends of the side spans is likewise an architectural improvement. The effect upon the eye caused by it, will be somewhat similar to that produced by the camber of the Bridge.

Of course these changes involved the necessity of revising the former investigations and results, so as to ascertain the difference in the strains, and to determine the alterations required in the sectional areas of the various members of the structure, when thus modified. An entirely new set of detail and general drawings were likewise required in consequence of these changes.

The lithographic view of the Bridge in the appendix is a very correct representation of the structure as it has been definitely determined upon, and is now being constructed. This view also shows the depth of the bed-rock at the site of the different piers, and the depth of sand overlying it during ordinary stages of water.

CONDEMNATION OF LAND FOR APPROACHES.

Since my last printed report, the land required in Illinois for the eastern approach to the Bridge has been obtained by condemnation, and paid for by the Company.

Judicial proceedings have been commenced in this State for the condemnation of the requisite ground for the approach on this side of the river. About one-fifth part of that which will be required has already been obtained by purchase. A commission has been appointed by the Court to fix the values upon the remaining pieces wanted. No delay in obtaining possession of all the land required is anticipated. These matters are entirely under the control and in the charge of the Executive Committee.

WIDENING THE AVENUES TO THE BRIDGE.

During the last session of the General Assembly of the State of Missouri, a law was passed requiring an election to be held by the citizens of St. Louis to decide upon the question of taxing the city with a sum not exceeding $500,000, to defray the cost of widening the streets leading directly to the Bridge. This election was decided affirmatively by a very handsome majority. Steps have already been taken by the Mayor of St. Louis, Hon. Nathan Cole, to carry the will of the people, thus expressed, into effect.

Washington avenue is the most centrally located avenue in St. Louis, and is also one of the most beautiful. It runs nearly in the direction of the Bridge, which is located at its eastern terminus. By the Bridge this avenue is virtually extended across the Mississippi River into the State of Illinois. The law referred to requires this avenue, which is 80 feet wide, to be widened at Third street, where the roadway of the Bridge begins, to 140 feet, and at Fourth street to 117 feet.

Third street, which is intersected by the roadway of the Bridge, is at this point only 60 feet wide, and immediately south of the Bridge it is only 38 feet wide. The law contemplates the condemnation of the fronts of seven blocks on this street, three on one side and four on the other side, so that it will be 116 feet wide at the Bridge. This width will be maintained throughout two blocks north and one block south of the Bridge. From this latter point it will be gradually narrowed from 116 feet to 76 feet, in the length of the second block south. Thence south, Third street is but forty or fifty feet wide. The widening of Washington avenue will, however, afford easy access to Fourth street, which extends southwardly from the Bridge a mile or more in one uninterrupted width of 80 feet, by which the southern travel will be conveniently accommodated. North of the Bridge, Third street, or Broadway, as it is called, will afford one grand highway, 100 feet wide, to the northern limits of the city,

These improvements will no doubt be completed by the city authorities as soon as the Bridge is finished. They will contribute greatly to the appearance and beauty of it, and will vastly promote

the convenience of the public. The wisdom and liberality of those who voted in favor of providing these magnificent highways to accommodate the vast tides of travel that will hereafter flow to and from the Bridge, will be more fully appreciated when the structure is completed.

CHANGES IN THE BED OF THE RIVER.

I think the propriety of placing the channel piers of the Bridge upon the bed-rock can be no longer questioned, if we consider the facts developed in sinking them. The remarkable scour of 51 feet below low-water line made in the bed of the stream at the east pier by the freshet of last April, is sufficient to prove that the scour extends much deeper than was supposed to be possible by many distinguished engineers. The depth of scour was assumed by them as never exceeding 30 feet below low-water mark. At more than twice this distance below low-water mark (66 feet) pieces of bituminous coal as large as a cocoanut were found imbedded in the sand at the site of the east pier. This coal had evidently been mined by man, and had not been carried any great distance by the current, as its surfaces were brilliant and the angles which had been formed by fracture were sharp and perfect. From these facts it would seem evident that the coal must have been carried by the current to where it was found, after the era of steam navigation, as we have no knowledge of stone coal having been used on the Mississippi before that period. These pieces of coal had doubtless been lost from some steamer navigating the river above the city, and lodged where they were found during a deep scour, resulting from some unusual under current acting upon the bed of the stream. These currents, I am convinced, extend to a greater depth in the winter season than in time of floods, which occur in the spring and early in the summer.

The channel opposite this city is very narrow, and during severe winters it usually freezes over very firmly before many wider places above are closed. From these open parts floes and fields of ice float down and are driven under the fixed and frozen crust at this point. The floating ice, being lighter than the water, occupies the part of the channel immediately beneath the frozen crust, and there stops, and as this engorgement in the narrow channel is increased by constant accessions from above, the current must be gradually forced deeper and deeper. In this way it is not at all improbable that where these gorges occur in the river its sand deposit may be totally removed in mid-channel and the bed-rock exposed to the action of the current. When this occurs a continuance of the supply of floating ice soon chokes the passage of the water between the rock and the gorged ice, and thus a natural dam is created across the stream. Sudden rises of the river above these gorges, attaining in a few hours

several feet in height, are not at all unusual on the Missouri and Mississippi during severe winters. When they occur, the immense pressure of the water finally sweeps away the obstruction, and fills the open spaces in the river below, for miles distant, with ice so discolored with river sediment as to be scarcely capable of flotation, and giving ample evidence of its imprisonment beneath the surface.

Col. Roberts found a bone in the sand within a foot or two of the bed-rock, under the east pier. It is a part of the femur, or thigh bone, of an animal larger than man, and is not petrified; from which fact I assume that it could not, probably, have been in the place where it was found during any long period of time.

While on this subject I will state, as an interesting geological fact, that a piece of the bed-rock was broken off in which is found a considerable amount of white coral. It appears on the surface of the piece, which is about three inches thick, and extends through it, appearing on the lower or fractured side. The walls of the cells are incrusted with quartz, the crystals of which are so minute that they can only be seen through a lens.

Beneath the west pier logs partly charred were met with at the depth of fifty feet below low-water mark. During the last pumping of sand from the east air chamber, eighty-four feet below low-water mark, particles of charcoal were constantly discharged from the pumps with the sand.

The bed-rock was found to be of dark-colored limestone, or marble, of such close texture as to admit of a moderate degree of polish. Its surface was worn smooth and covered with corrugations of from three to six inches in size, evidently proving that it had been exposed to the direct and constant action of the current, probably at some very remote period.

THE ICE-BREAKERS.

The lateness of the season when the sinking of the east pier commenced made it absolutely necessary to provide some adequate protection for the requisite boats, machinery, etc., at the site of the pier, against the heavy floating ice which invariably makes its appearance here during the winter. This floating ice frequently attains a thickness of ten or twelve inches, and often covers the entire surface of the river, moving along at the rate of about three or three and a half miles per hour. In proportion as the weathar becomes more intensely cold, the volume of the ice increases, and the rate of its movement decreases, until it finally comes to a full stop and then quickly freezes over, affording, even within a few hours afterwards, a safe highway across for pedestrians. In a day or two later the frozen mass becomes so strong as to support the largest and most heavily-loaded wagons.

The freezing over of the river at St. Louis is not, however, an invariable rule, as it does not occur, perhaps, oftener than three in every four years on the average. Last winter was fortunately an exception to the rule. For several days, however, the floating ice was so heavy and compact that it was with the utmost difficulty that the most powerful steam ferry boats, built expressly to meet such contingencies, could force a passage through it. One or two trips across during an entire day being all that they could acomplish, frequent attempts in the meantime proving abortive.

To establish in mid-channel any temporary works to withstand an element so apparently resistless, and of such exhaustless volume, was an untried experiment on the Mississippi that presented several very discouraging features. The two chief difficulties were, first, to place any construction above the pier that would not be quickly scoured out by the current, and, second, to make such construction so strong as to resist the power of the ice to sweep it away. The method devised by me to accomplish the desired result will be fully understood by the following description.

About two hundred feet above the pier, at a point from whence the current would flow to the centre of the pier, a pile was driven which formed the apex of a triangular system of piles shaped like the letter A. From this pile two lines of other piles were driven at distances of eight feet. These two lines extended down stream to the distance of two hundred feet, and represented the two sides of the letter A. At their lower extremities these two sides were about one hundred and eighty feet distant from each other. The triangle thus formed was filled in with other piles driven in transverse lines from side to side at distances of about fourteen feet, and the tops of the entire system were then thoroughly braced together with hewn oak timbers ten by ten inches square, well bolted to the piles, which were of cypress.

The water was from forty to forty-seven feet deep when this part of the work was executed, and many of the piles were washed up as the work progressed. It was difficult to drive them into the sand more than twenty feet deep, even with a steam pile-driver of 3,500 pounds weight.

About fifty feet above this triangle was placed a clump of nine piles driven close together, and this was encased in sheet iron throughout about twelve feet of its length, to prevent the ice cutting the piles. About one hundred and fifty feet above this clump of piles a large iron pile made of the shell of an old cylindrical steam boiler five-sixteenths of an inch thick, twenty-eight feet long, and forty-two inches in diameter, was sunk nearly to its full length into the sand vertically. From the middle of this iron pile, twelve feet below the river bed, was attached, before sinking, a wire cable of one and seven-eighths inches in diameter. This cable was led over the clump

of piles and firmly secured to it, and from thence it was carried down to the apex of the triangular system below, where it was hauled taut and securely fastened. The object of the rope was to aid in holding the piles steady until the entire protective system was completed; and also to form a cutting edge on which the large floes of ice could be raised and broken asunder before striking the works below. To the triangular system of piles the caisson was secured, and was held by it against the current until it entered the sand.

The iron pile was open through six feet of its lower part to form a sand chamber into which one of the sand pumps was introduced to withdraw the sand and permit it to sink. Above this chamber the pile was filled with ore from the Iron Mountain of Missouri, to insure its sinking in the sand. A central tube fourteen inches in diameter, made of an old boiler flue, enabled the sand pump to be passed through the pile to the sand chamber at the bottom; the ore being contained in the annular space surrounding this tube. The water was about thirty-five feet deep at the site of this pile when it was sunk. After its lower end had penetrated to a point about sixty-two feet below the surface of the water, and the cable had been tightly stretched, fifty or sixty cubic yards of large rubble stone were thrown in around the pile to protect it from scour.

After this work had progressed thus far, a subsidence of about ten feet in the river enabled us to bolt on to each side of the triangle of piles, about ten feet below their tops, a longitudinal timber about ten inches square, running the entire length of the system. These two longitudinal timbers placed near the surface of the water, and well secured to the sides of the triangle, constituted hinges by which two enormous ice aprons were attached, one on each side, to the triangle.

The object of these aprons, which will be presently described, was to present an inclined surface on each side of the triangle of piles on which the impact of the ice should be received. Any obstruction opposing a vertical surface to the action of the ice would be soon crushed to pieces or ground away, whereas by presenting an inclined one the ice would slide up on it and be broken to pieces, and be thus made to pass off harmless from it, just as the soil does from the plowshare and mould board.

To protect the piles from the scouring action of the current, it was necessary to provide some means of keeping the current from them. To do this with broken stone would be very expensive as well as unreliable, and would besides create an obstruction much larger than the pier, which would be difficult and costly to remove after the masonry was completed. By planking the ice aprons down their inclined sides to the very bottom of the river, the current could be deflected by them from the piles below, and the ice from them above, and thus both objects be attained. This was done.

The ice aprons were two hundred feet long and sixty feet wide. It was necessary to place them beneath the water at an angle of forty-five degrees, and with the lower edge or side of each resting on the sand, and to make them of such strength as not only to resist a powerful current, but also to withstand the great pressure of the ice, which might by the fluctuations of the stream be made to impinge as low down on their sides as to the middle of their surfaces, as well as at twelve or fifteen feet above that point.

The frames of the aprons were made of strong squared oak timber, placed transversely at intervals of eight feet, so that the upper end of each one of them would rest by the side of a pile, and on the longitudinal timbers before mentioned. The transverse timbers were each sixty feet long, and were held in place by three equidistant string pieces, each two hundred feet long, bolted beneath them. Two of these skeleton frames were thus constructed on shore, above the works, and were launched with sufficient pine timber beneath to float them. They were then towed, one to each side of the pile structure, and the end of each transverse timber on the side next the piles was placed on the longitudinal timber or hinge before named and secured temporarily to them by chains. The outer edges of these frames were then secured to barges placed alongside of them, and the pine floats under the frame were then taken out. In this position as the two frames lay on the water they were planked with three-inch oak plank. On that part where the ice was expected to impinge, No. 16 sheet iron was placed over the planking. A space on each apron about twelve feet wide and extending their entire length was thus covered with iron. Below this iron covering some openings were left through the aprons for the current to pass, to prevent the formation of a bar of sand below the structure in the eddy that would be created by the ice aprons, after they should be in place.

When the aprons were both completed, the lines holding up their outside edges at the barges were simultaneously cut away; these edges then quickly disappeared beneath the current, and were swept by it to the bottom. Both aprons assumed the desired angle. The upper extremities of the transverse timbers forming them then rested upon the longitudinal timbers forming the hinge by which their lower ends were rotated down to the bed of the stream. The upper ends of these transverse timbers were then each bolted to its respective pile, and that portion of the sides of the pile system extending vertically above the aprons was planked with two or three strakes of ten by ten oak timber, at the part nearest the aprons, and above that point with lighter oak plank. At the apex of the breakwater thus formed about one hundred and fifty cubic yards of rubble stone were thrown in, to thoroughly close any space left between the upper ends of the two aprons.

This structure sufficed to completely turn the ice during the winter,

and made a thorough protection to the works and barges about the pier. A deposit of sand rapidly formed behind the ice aprons which gave great support to them, whilst they in turn protected this deposit, once formed, from the action of the current.

Before our magnetic telegraph was erected, the ice was so heavy for several days as to completely suspend intercourse between the workmen at the pier and the shore. This contingency had been provided for by provisioning the men with two weeks' rations and providing them with bedding.

During the greatest severity of the ice, Mr. McComas, who remained at the pier, continued to operate the sand pumps, and every morning and evening reported the progress of the work in a conspicuous place, and in characters so large as to be read by telescope from the shore. The closing sentence of the report was constantly, "Ice-breaker all right."

This structure was duplicated at the west pier with equally successful results. Both ice-breakers are still standing, having successfully withstood the April flood, which attained a height of twenty-six and a half feet above low-water mark, and although the current is much increased by them and the river bed scoured out in proportion, the original angles assumed by the aprons seem to be almost entirely unaltered.

CONCLUSION.

I avail myself of this opportunity to express my thanks to the several gentlemen assisting me in the various departments of the Engineer and Construction Corps of the Bridge, and to commend them to the kind consideration of the Company, for the faithful and efficient discharge of the important duties assigned them.

Respectfully submitted.

JAMES B. EADS, *Chief Engineer.*

REPORT

To the President and Directors of the Illinois and St. Louis Bridge Company, October 1, 1871.

Gentlemen,—I have the honor to make the following report:

MASONRY.

The total amount of masonry of every kind, including brick-work, laid up to this date is sixty-eight thousand seven hundred and thirteen cubic yards. There remain yet to be laid thirty-three thousand nine hundred and two cubic yards.

EAST APPROACH.

The foundations of the five piers and towers of this approach have all been built, and are now completed ready to receive the sandstone, excepting pier No. 2, the red granite being laid up, including the wash-course, on all of them with this exception.

These approach piers (excepting No. 5, to which the towers are attached) were all sunk by the same process used in sinking the large ones. This was believed to be more certain and economical than by coffer-dams, the method used on the west approach. The result has fully confirmed this opinion. With pier No. 2 the coffer-dam would have proved very expensive, as this pier encountered in its descent the hulk of an old and strongly-built ferryboat. Its planks were three inches thick, and floor timbers four by eight inches square. This hulk had to be cut away to permit the descent of the pier, which has gone directly through it, the kelson of the wreck having been intersected by the caisson. This not altogether unexpected difficulty has delayed the completion of this pier about three weeks. It has now passed this obstruction, and needs to be sunk only one foot more to reach its final destination.

It has not been deemed necessary to sink the foundations of the first four piers of this approach deeper than twelve feet below extreme low-water mark. The caissons used are made wholly of oak timber, excepting only the air-locks and the spikes and bolts used

in fastening the timbers together. They are ten feet high; consequently they are entirely below low-water line, while the masonry extends only down to that line. The surface of the wharf will be about nineteen feet above the bottom of the foundation of No. 1, and about thirty-two feet above that of No. 4.

The towers and pier No. 5 are laid on a foundation of concrete six feet deep, under which a system of piles was first driven to an average depth of twenty-five feet. The concrete is based fifteen feet above low-water line.

The east abutment pier, resting on the rock at the depth of 136 feet below high-water mark, and standing between these approach piers and the river; and the wharf pavement covering the river shore, will, I think, be amply sufficient to prevent the current of the stream from ever affecting the foundations of these small piers.

From the towers eastward the upper roadway of the Bridge will be carried by trestling to Fourth street in East St. Louis, with a grade of four feet to the hundred feet. The railways will curve out to the north from under the upper roadway, immediately east of the towers, and will be of such grade and construction as shall be determined upon by the railroad companies who have contracted to use the Bridge, and who will pay for these railways. A sixty-eight foot grade will bring the railways down to the level of the present tracks in East St. Louis, within a distance of about 3,000 feet.

EAST ABUTMENT.

This pier has had no work done upon it during the last four months. It is completed on the river front to within two courses of the wash-course. The wash-course is the one immediately below the lower tier of skewbacks.

On the T wall the red granite is now being laid, four courses being required to finish it ready for the sandstone. The sandstone commences upon the wash-course, which course in the T wall is of red granite, and corresponds in height with the wash-courses of the approach piers on each shore.

EAST PIER.

The masonry of this pier lacks two courses of being high enough to set the lower tier of skewback plates. These will be laid while the contractors are setting the plates on the west pier; there being but one outfit of hoisting apparatus for carrying up the masonry of these two piers, it is alternately used at each. At present no work is being done on this pier. It will, however, be finished considerably in advance of the wants of the contractors for superstructure.

WEST PIER.

The masonry of this pier has been carried up high enough to receive the lower tiers of skewback plates, where it must rest until these are fixed against it. The stone-cutters are now engaged in making the necessary recesses in the granite to receive the plates, and so soon as this shall have been completed, these plates will be set. This pier will be completed about the first of February next. The necessary steel and iron-work for it are in such a state of forwardness that no further delay need be feared in its completion.

WEST ABUTMENT.

The masonry has been carried upon the T wall or western face of this abutment to a level four courses below the springing of the first stone arch over the St. Louis wharf. This portion of the masonry (the T wall) is of sandstone. On the river front of the pier the masonry is finished to a level five courses lower than the T wall, and is now ready to receive the lower tier of the skewback plates. These four plates are now ready, and will immediately be set by the contractors for the superstructure. So soon as this shall have been done, the masonry of this side of the pier will be carried up to receive the second tier of skewback plates.

These skewback plates are 7 feet by $3\frac{2}{3}$ feet 6 inches in thickness; and to insure an equal bearing against the granite throughout their entire area, iron cement will be driven in between them and the stone after they are in proper position. This work must be done before the next courses of granite are laid above the plates. These plates will sustain the entire thrust of the arches. It is against them that the skewbacks of the arches will rest. The skewbacks are of wrought-iron, and will be firmly secured to the masonry by large anchor bolts passing through them and the skewback plates into the abutments, where the bolts will be fastened to cast-iron anchor plates built in with the masonry. Into the upper and lower tiers of skewbacks the cast-steel tubes which form the upper and lower members of the arches will be inserted. The anchor bolts are $5\frac{1}{4}$ inches in diameter. Some are made of steel and others of iron, according to the different degrees of strain to which they will be subjected. The lower skewbacks will each have four bolts and the upper ones three. These bolts will sustain no portion of the weight of the arches. Their object is simply to prevent any movement at the ends of the arches, which would otherwise occur from extremes of temperature and excessive inequality in the distribution of load upon the arches.

When the second tier of skewback plates are fixed upon this abutment, the remainder of the masonry of it will be rapidly completed.

I see no reason now to fear any further delay in this part of the work, and think the masonry of this pier will certainly be completed by next February.

WEST APPROACH.

The piers of this approach over the St. Louis wharf are all up to the springing of the arches which they are intended to carry, except pier No. 5.

One complete sandstone arch is turned upon piers Nos. 2 and 3, and about one-fourth of an arch is turned upon the centreing on each side of this completed arch. The other two arches of this approach cannot be started until the T wall of the west abutment is four courses higher, and pier No. 5 is completed. This pier stands in the house line of the wharf, and is completed from the rock to the wash-course inclusive, and is therefore ready to receive the sandstone on the red granite base-course.

The foundation of the south tower is also completed to the same extent, and sandstone is being laid now on this pier and tower. The foundation of the north tower has just been commenced.

Between the wharf and Commercial street the masonry is well advanced, piers No. 6, 7, and 8 being completed. On these piers is now being placed the centering for the brick arches which will surmount them, each arch having twenty-seven feet span.

Piers Nos. 8 and 9 stand on opposite sides of Commercial street, twenty-seven feet apart. Each is completed ready for the centering of the arch, which will soon be placed in position on them.

Piers Nos. 9, 10, 11 and 12, standing on the block between Commercial and Main streets, are all completed, and the three brick arches (26½ feet in diameter) upon them are likewise completed. The spandrel spaces between these arches are being filled with ballast to level up for the railway sleepers. The vaults under the arches between the wharf and Main street are inclosed by substantial masonry, and the rooms thus formed are connected by arched doorways through the piers. A large warehouse is thus created on each of these blocks, which will be available for revenue. Arched entrances are provided to these apartments through the piers on Main and Commercial streets.

The land over which the approach is carried further west is similarly utilized for warehousing purposes as far as to the middle of the block between Second and Third streets.

Pier No. 12, now finished, forms the eastern abutment on Main street for the support of the truss which carries the roadways over that street.

Pier No. 13, on the west side of Main, is built up from the rock to the street level, and the sandstone work on it is progressing. From

this point west no large piers occur, except on each side of the alley between Main and Second, and on each side of Second street, at which point abutment piers are being placed to sustain the iron trusses for carrying the roadways over these thoroughfares. The foundations for all of these abutments are built up to within one or two feet of the street levels, and sandstone work is progressing on one of them on Second street. The others are covered at present with hoisting machinery and wagon ways for transporting materials. From Main street to the middle of the block, between Second and Third streets, the railways and roadways will be supported on strong side walls of masonry and two rows of brick pillars placed equidistant between these walls. These side walls are almost entirely completed, ready for receiving the railway timbers, from Main street to the end of the approach at Third street. Betweed Second and Third streets they are still more advanced, being nearly completed for the upper roadway.

The brick pillars between these side walls are well advanced east of Second street to the alley, one tier being nearly completed to the level of the railway beams.

The entire masonry for the west approach, from the Levee to Third street, will be completed ready for the superstructure, I think, by the middle of January next.

SUPERSTRUCTURE.

CAST STEEL.

The Keystone Bridge Company, contractors for superstructure, have made but little progress in their contract, owing chiefly to delays in obtaining the proper quality of steel and iron for the work. The contract for steel was let by them to the Wm. Butcher Steel Works, near Philadelphia. Extensive additions, consisting of buildings, furnaces, rolling-mill, straightening machines, etc., were made to the works, and every indication seemed to encourage the belief that the steel would be promptly supplied. Unforeseen delays, however, occurred in getting the necessary machinery into proper working order.

The first large forgings required by the Bridge were steel anchor bolts, five and three-quarter inches in diameter, and from twenty-two to thirty-six feet long. The first bolts, when tested, were found to be of inferior quality. Having been injured in forging, they were broken by testing. Each bolt is required to sustain, when tested, a tensile strain of 519 tons, without being permanently elongated, being twice as much as the maximum strain to which it can be subjected in the

Bridge. Before this test could be applied to the defective ones sufficiently to prove their weakness, the testing machine itself was broken twice. This involved several weeks' delay. When the defects of the machine were remedied, the inferiority of the bolts was fully discovered. New mixtures of steel had then to be tried, and greater care was used in its manipulation. Many bolts had been made before the testing machine was repaired and could reveal these defects. These were, of course, rejected when tested, and others had to be made in their stead.

In the novel operation of testing such large forgings, and in the management of the machine itself when exerting such great strains upon them, many unexpected accidents occurred, both to the machine and to the instruments required for measuring the extensions of the bolts and the amounts of strain imposed upon them. For instance, a piece of one of the bolts, which weighed over 1,000 pounds and twenty feet in length, was shot out of the machine like an arrow when the bolt broke, and fell fifty or sixty feet distant; whilst the other end of the bolt reacted with such force upon the machine as to break the piston rod or pulling bolt by reversing the tensile strain upon it, thus driving it out of the ram at the other end of the hydrostatic cylinder, and breaking by its reactive force the fastenings by which it was secured.

The expense of testing was assumed by the Keystone Bridge Company in its contract, and it in return sub-let this part of the work, so far as it relates to the steel, to the Wm. Butcher Company. The design, construction and repairs of the necessary testing machines and appliances are, therefore, a part of the province of the contractors, they simply agreeing to subject the various materials to the requisite strains under the supervision of the Chief Engineer of the Bridge, or of his assistants, the instruments by which the strains are measured being all that is supplied by the Bridge Company.

By these various delays several months were lost before any bolts were supplied, capable of sustaining the strain above named. These difficulties were, however, fully overcome, and twenty-four bolts have been tested and received. Eighteen of these were sent more than three weeks ago to the Keystone Bridge Works, at Pittsburg, to have screws cut upon them. Others are being made from day to day at the steel works, and I believe they will now be supplied as fast as they are needed. Twenty-six are yet to be made.

Similar difficulties and delays were experienced in other parts of the steel works. About four-fifths of the entire steel required consists of tubes about thirteen feet long and eighteen inches in diameter. These are each composed of six staves of the length of the tube, and varying from one and one-eighth to two and one-eighth inches in thickness, and each being about nine and one-half inches wide. Several attempts were made to roll these staves before the rolls were per-

fectly formed to accomplish it. Each failure necessitated the removal of the rolls from the mill for alteration to the machine shop, several miles distant. Each of these rolls weighed several tons, and this usually involved a loss of two or three weeks before they were in place again and ready for trial.

An option had been given the contractors to have these staves rolled with a rib on each edge of the stave and projecting into the tube, or to roll them without these ribs. The steel company elected to roll them with the ribs. After three or four alterations of the rolls they determined to abandon the attempt to roll them with the ribs. This involved the making of an entire new set of rolls, ten or twelve in number, and when these latter were tried they had to be twice or thrice returned to the machine shop before perfect staves could be turned out with them.

In this way at least six months were consumed before a stave could be offered for testing. When this was done the steel proved inferior. Repeated changes had then to be made in mixing the steel. When a satisfactory mixture was obtained it was only then discovered that the same degree of strength was not present in all the staves made from it. This was believed to result from a want of proper care in melting and in forging the ingots, and in second heating for rolling. No doubt the difference in the degrees of heat applied to the perfect and imperfect ones altered the proportions of carbon and iron, or their relations to each other, and thus caused a decided difference in the strength of the staves thus made from the same formula. Of the anchor bolts, about twenty on twenty-two which stood the test were carbon steel, while nearly an equal number failed under it, although many of the failing ones were made by the same formula as the good ones.

These results proved the absolute necessity of using the greatest skill and caution in the application of the requisite degrees of heat in making carbon steel. The want of this extraordinary care has caused great loss of time and money to the Bridge Company, and has doubtless occasioned serious loss to the Butcher Steel Works. This unfortunate experience induced that company to endeavor to find some other method which would insure with less skill and caution a greater uniformity of product. With this view, experiments were commenced at the works recently in making chrome steel, under the patents of Mr. Bauer. These trials were under the direction of Mr. C. P. Haughian, Superintendent of the Chrome Steel Company, and were attended with the most satisfactory results. An arrangement has since been made with the patentee for manufacturing this steel.

Chromium unites with iron and forms an alloy, similar in its properties to steel. Chromium is quite different from carbon in some important particulars. It is a metal, while carbon is not. It has little or no affinity for oxygen, and is not affected by excessive heating,

while carbon has a great affinity for it, and by the application of heat it is liable to be burnt out of the steel.

One hundred trial staves were made last month of chrome-steel, under the directions and from the formula of Mr. Haughian. They were all beautifully and perfectly rolled, and there was no failure in any one of them to stand the test required. This steel comes from the rolls much more smoothly than the carbon-steel, and it works quite as easily; being capable of sustaining a greater degree of heat than the carbon-steel, it takes the form of the rolls more readily.

Tests made of this steel by me, before the contract was made with the Keystone Bridge Company, satisfied me that it possessed qualities eminently suited for the Bridge superstructure.

In 1869 Mr. Haughian allowed me to be made acquainted with the entire process of manufacturing chrome-steel. Commodore J. W. King, of the Engineer Corps of the Navy, now Chief of the Bureau of Steam Engineering, kindly volunteered to investigate the subject for me, and on my personal pledge that Mr. Haughian's trade secrets should not be revealed, Commodore King and my chief assistant, Colonel Flad, were allowed to pass forty-eight hours in the closest inspection of the works, during which time they weighed out the proper mixtures, placed them in the crucibles, melted them, cast the ingots, and had the steel finished by the hammer, all being under their immediate supervision. An elaborate confidential report was afterwards made by them to me of their observations and experience.

As it was, however, a patented manufacture, and made by but one establishment, to have required it to be furnished by my specifications would have been equivalent to compelling the Keystone Bridge Company (whose contract with your company was made before my specifications were complete) to forego all competition in obtaining the steel; and as several other makers expressed the fullest confidence in their ability to furnish an equally reliable steel, it seemed but fair to state the necessary qualities which the steel should possess, without prescribing any special formula that would restrict competition.

I did not feel justified in assuming that crucible carbon-steel of the qualities and forms required could not be readily made, when I was assured of the contrary by some of the most eminent steel makers in America. I was so fortunate as to be permitted to make a careful personal examination of Mr. Krupp's great works in Prussia, and also the mammoth works of Messrs. Petin Godet & Co. in France, and was also assured by the managers of both of them that our requirements were entirely practicable with carbon-steel. I did not, however, hesitate at any time to express my belief that the chrome-steel was most likely to meet the requirements of the Bridge; nor am I justified now, perhaps, even with the experience developed at the Butcher

Steel Works, in asserting more than my opinion that carbon-steel cannot be made with as equal regularity and uniformity as the chrome-steel.

I think the sequel has proved that it was unfortunate for your interests that a contract for chrome-steel was not made at first, for the usuccessful attempt to supply the carbon-steel for the Bridge by the Wm. Butcher works has seriously delayed its completion.

While this disappointment has resulted in great loss to you by the delay it has involved, it must have inflicted serious damage upon the Wm. Butcher Company. The honorable disposition shown by the latter company to discharge the obligations of their contract with the Keystone Bridge Company, and furnish a quality of steel fully equal to their agreement, notwithstanding their many unexpected losses and disappointments, certainly merits your considerate notice. The President of the company, Mr. Samuel Huston, has repeatedly assured me of the determination of himself and associates to supply the Bridge steel as promptly as possible; and that they asked no abatement in its quality, but were resolved to make it fully equal to the requirements of the contract, cost what it would.

Acting upon this commendable determination, that establishment has contracted to pay Mr. Haughian a royalty of $15,000 for the right to make chrome-steel for your Bridge; and I have been assured by Mr. Huston that henceforth no other kind of steel but this would be made for it.

From what I know of the manufacture of chrome-steel, and from the tests of anchor-bolts, staves, and envelope plate-steel, already made at the Wm. Butcher Works, from the formulas of Mr. Haughian, I feel every assurance that the difficulties in the way of supplying the steel for your Bridge are now surmounted. The steel we are now testing is of a quality entirely satisfactory, and the workmanship is unexceptionable. The tests made of its ultimate tensile strength are considerably in excess of the specifications. In compression almost any degree of resistance can be obtained by the addition of chrome. To avoid unusual difficulty, however, in finishing the steel in the lathes, it is only made sufficiently hard to meet the requirements of the specifications.

IRON-WORK.

I regret to state that our iron-work is not being prosecuted by the contractors with due diligence.

The Keystone Bridge Company contracted with other parties (as I am informed by Mr. Linville, President) to make the main braces which connect the upper and lower members of the arches together. These members are scarcely second in importance to the steel tubes

which compose the arches. They are to be made of iron, and I was informed by Mr. Linville that my specifications form part of his contract with the sub-contractors. These specifications distinctly state how the iron shall be tested, and that it shall bear an ultimate tensile strain of 60,000 pounds per square inch. None of the iron yet offered by the sub-contractors has proved capable of bearing over 54,000 pounds, and very few samples have exceeded 50,000 pounds, and much of it only about 48,000 pounds. I have recently been assured, however, by Mr. Linville that the sub-contractors will supply the iron, without any further delay, fully up to the standard required. As several other parties have offered to furnish the requisite quality, and have proved their ability to do so by the tests already made of their iron, we have reason to believe that the Keystone Bridge Company will not be longer delayed in obtaining it from the parties with whom they have contracted, or from other makers.

FINANCIAL.

Statement No. 1 in the appendix gives the amount of money yet needed to complete the Bridge. Statement No. 2 exhibits the amount charged to construction by the Auditor up to the 1st of September, 1871.

From these two tables it will be seen that the cost of the Bridge will exceed the original estimate $1,479,582.72.

Justice to myself, as well as to you, demands an explanation of the causes which have led to this difference in cost. For this purpose Statement No. 3 in the appendix has been prepared. It is based upon the actual expenditures to September 1, 1871, and the estimated cost of the work yet to be done. An examination of it will show the various items of cost of the work over and above that contained in the original estimate.

In my report of last October I referred to the fact of a scour of fifty-five feet in vertical depth having occurred in the river bottom alongside of the east pier, and of the proofs that were met with in sinking that pier, that the scour at times extended even to the rock itself. It was generally assumed by others who had studied the peculiarities of the river that the scour never extended deeper than thirty feet below low-water mark. Although I believed it extended much deeper, and that there would be no assurance of stability for the *channel* piers unless founded on the rock, I believed, when designing the Bridge, that the abutment on the Illinois shore could be made safe on a pile foundation. The original estimates, therefore, only contemplated a foundation of this kind, with the base of the masonry starting from a level seventy feet above the bed rock. The possibility of founding this abutment on the rock having been dem-

onstrated by sinking the east channel pier, and the proofs of scour of the river bed to such extraordinary depths being perfectly conclusive, the Board expressed the unanimous desire that this abutment should be founded on the rock. By an examination of the appendix it will be seen that the cost of this extra work was $232,626.64, no part of which was in the original estimate.

The original design of the Bridge contemplated an upper road-way wholly of wood. The substructure of this roadway was designed to act as a truss to resist the action of hurricanes upon this part of the Bridge. As now designed, this substructure or wind-truss will be in the form of a flat or horizontal girder fifty-four feet wide extending from pier to pier, and formed entirely of plate-iron, thus giving much greater security against wind, and furnishing a fire-proof defense for the upper roadway against the sparks and heat from the engines when passing on the railways below. The wonderful force exerted by the tornado last March, which was so destructive in its effects upon the construction works of the Bridge Company, leaves no question as to the propriety of this change. Nothing equaling the power of this storm is believed to be on record. A locomotive of over twenty-five tons weight was actually hurled from the rails by it, and was thrown over on its side twenty-five or thirty feet from the track, on ground only four or five feet lower than the rails. No evidence of the engine disturbing the rails, or of touching the earth within twelve or fifteen feet of the track, could be discovered. These facts were reported to me by my Chief Assistant, Col. Henry Flad, who personally inspected the spot immediately after the storm.

From calculations based upon the data furnished by this tornado, I feel confident in asserting that the arches of the Bridge will be capable of resisting an equally powerful tempest. The extra cost involved in substituting this plate iron wind-truss for the wooden one will be $80,000.

The destruction of machinery, scaffolding, etc., caused by the tornado, with incidental expenses caused by it, cost the Company fully $50,000.

In my report last October, I stated the fact that the Company had incurred serious losses, caused by the failure of the first contractor for granite. I then explained how these losses ensued, and stated their total amount to be fully $50,000.

From July, 1869, to May, 1870, owing to financial embarrassment, little or nothing was done in the construction of the Bridge. The official and other expenses throughout this period of inaction, not calculated for in my original estimate, were not less than $35,000.

The original estimate contemplated granite ashlar on the piers and abutments, from two feet below low-water line to high-water mark. It was afterwards determined to encase the four main piers with granite to their tops. This extra quantity of granite cost $73,476.

The items of granite masonry were originally estimated at $32 per cubic yard. The price paid was from $14.94 to $20.76 in excess of this. After the failure of our first granite contractor, although the entire granite quarries of the East were canvassed, we were compelled to pay these higher rates to the subsequent contractors. The excess of cost in this item over the original estimate is $94,149.

The original estimate contemplated an extreme width of fifty feet for the Bridge. This has been increased to fifty-four feet two inches. Several reasons made this change desirable, if not absolutely necessary. By the increased width, twelve inches of additional space between the arches are obtained for each railway track. This is believed to be an important improvement, and one which was rendered desirable from the increased width given to the Pullman palace cars since the original design of the Bridge was made, in 1867.

On the upper roadway the local traffic will be more conveniently accommodated by this change. Two lines of horse railway cars are provided for on it, with room on either side of them for the largest transfer wagons. The sidewalks will be nine feet wide, instead of eight. In addition to these desirable advantages, the general appearance of the structure will be considerably improved. The most important consideration, however, in determining upon this modification in design, was the increased security afforded by it against violent winds.

The extra cost of widening the Bridge four feet and two inches is estimated at $127,652, and the additional land damages at $30,000.

The cost of tramways for street or horse cars was not included in the original estimate. This item amounts to $19,113 29.

The original estimate contemplated arches eight feet in depth, with the railway tracks below the central parts of the arches. The depth of the arches has been increased to twelve feet, and the railways raised up flush with the lower part of the arches at their centers. The change in the grade of the approaches caused by this alteration will cost $33,257.

The original design contemplated only two railway tracks on the approach between the Levee and Third street, in St. Louis. The side walls of this part of the approach have been widened, and an extra tier of brick pillars will be built in it, by which three tracks will be located there, instead of two. The cost of masonry, iron, etc., by this change will be $10,300. This alteration will very materially increase the railway facilities of the Bridge.

The cost of widening the iron bridges over the streets and alley to accommodate this third track will be $6,000. The switches required to connect these three railway tracks together in this approach prevent the use of posts to support the upper roadway where they occur, and involve the necessity of using iron girders at an extra cost of $19,800.

The four towers of cut sandstone at the ends of the Bridge, in which the stairways will be placed, will cost $30,000 over the original estimate.

The grade of the upper roadway trestling in East St. Louis has been altered from five to four feet in 100. This increases the length of it 476 feet and the cost $28,000.

In consequence of unforeseen and unavoidable delay on the part of the contractor in getting the three caissons for the east abutment and channel piers ready early in the season, the sinking of each of these piers had to be done chiefly in the winter. This involved the absolute necessity of protecting them from the ice by putting ice breakers in the channel above each one of these piers. This was an unforeseen expense, amounting—

At the east pier to	$31,346 53
At the west pier to	33,088 33
At the east abutment	11,000 61
Total	$75,525 47

The cost of sinking the east pier is found to exceed the original estimates by $76,990 66.

The cost of sinking the west pier exceeds the estimated cost $35,-442 29. The cost of sinking the west abutment, owing to several steamboat wrecks which were found imbedded in the wharf extension at the site of this pier, exceeded the original estimates $47,-770 80.

The original contract for superstructure was made with the Keystone Bridge Company before the detail drawings and specifications for the work were fully completed. The reasons for this unusual proceeding were deemed of sufficient moment by the Directory to justify it, but it caused several misunderstandings between the contracting parties, and resulted in the making of a supplementary contract in which, among other concessions made to the contractors, was one in the item of forty-eight wrought iron skewbacks. The Keystone Bridge Company asserted that they made the agreement under the misapprehension that these forgings were to be of cast iron. Your Company consented to exclude these members from the contract and to pay actual cost for them. By this concession the cost of the superstructure is estimated in Statement No. 2 to be increased fully $30,000.

It will be seen by aggregating these various items that $1,179,097 15 of the $1,479,582 72 of excess over the original estimates are accounted for by them, leaving $300,055 16, which has been expended, according to the accounts of the Auditor, in extra cost of machinery and various other incidental and contingent expenses, in excess of the original estimates.

I have no additional explanation to submit in accounting for this

difference between the original and the present estimated cost of the work, except to say that in computing the amount of contingencies liable to be met with in sinking foundations of such unusual dimensions, to such unexplored depths, and under conditions so very novel, I evidently under-estimated them, and have therefore, much to my regret, misled you. While I feel constrained, therefore, to ask your indulgence, I beg to call your attention to the difficulty of foreseeing or preventing such incidental expenses as some of those which are charged to construction account, and which go to swell this deficiency—such, for instance, as: "Hospital, medical attendance, and compromising suits, $9,569 21; law suits in Illinois, $17,087 66; legislation and similar expenses, $9,800."

Some compensation for the disappointment that must necessarily result from the delay in completing the structure, and from its increased cost over the original estimates, may be found in the fact that the estimated amounts of traffic upon which the revenues of the Bridge were predicated in 1868, have been ascertained, after a careful examination of actual facts and figures in 1870, by Mr. Wm. Taussig, Chairman of the Executive Committee, to be greatly under-estimated. It is confidently believed, from facts developed by this examination, that the income of the Bridge will be very largely in excess of the amount estimated in 1868.

With respect to the work remaining to be done, I do not think there can be a possibility of the actual cost differing materially from the estimates henceforth. It is all under contract, and the weights and amounts have been very carefully verified. I feel quite confident that the delay in the superstructure, which has retarded the entire work, and added very considerably to the expenses already incurred, is fast drawing to a close, and that before many more weeks we will see some of it in the course of erection.

The character of the work, as far as it is finished, is unsurpassed in excellence and solidity by anything in this or any other country. When finally completed, I feel confident that the magnitude of the structure, the superiority of workmanship, and the quality of materials used, will fully justify the total cost of its erection, and that its revenues will amply compensate for the investment.

When all of the many difficulties that have retarded this great work shall have at last been surmounted, and the Bridge becomes an accomplished fact, it will be found unequalled in the important qualities of strength, durability, capacity and magnitude, by any similar structure in the world. Its great usefulness, undoubted safety and beautiful proportions will constitute it a national pride, entitling those through whose individual wealth it has been created to the respect of their fellow-men; while its imperishable construction will convey to future ages a noble record of the enterprise and intelligence which mark the present times.

JAMES B. EADS, *Chief Engineer.*

BANK STOCK.

LETTER

To the Editor of the Missouri Republican, July, 1866.

Mr. Editor,—A few days ago you asked for information about the sale of the State's interest in the Bank of the State of Missouri. I propose to give you some information on this subject.

The agent for the sale of the stock advertised it for sale under the terms of the act of the Legislature; that is, that he would receive sealed proposals for the purchase of the stock up to the 4th day of June at noon.

I was a bidder, as was also the bank itself. There were several other bidders for the whole or part of the stock, of whom it is unnecessary to say more than that their bids were about seventy-five dollars per share.

The bank put in three or four bids: one in its own name for eighty-one and a half dollars per share; one, I believe, in the name of Jno. Sheldin, for ninety dollars; and two in the name of E. Shine, one for one hundred and four and one for one hundred and five and five-eighths per share.

I put in two bids: one in my own name for ninety-one and one-half dollars per share, and one in the name of J. T. Wilkins for one hundred and six dollars per share. All of these bids were for payment in State bonds and coupons.

I was the highest bidder, and the Governor having approved my proposal, the purchase was awarded to me, and I immediately began making my arrangements for the bonds with which to make my payments.

Subsequently I heard that the Governor had received from the bank a proposal to pay one hundred and eight and one-third dollars per share for the stock, and had transmitted that proposal to the

agent. (Here be it observed that the agent alone could receive proposals—not the Governor.) This action of the Governor alarmed me, as it indicated an intention on his part to repudiate the contract of sale to me, and I had already gone so far in the matter that I could better afford to pay some blackmail than to lose the purchase, or enter into a controversy with the Governor, backed by the bank. I therefore again outbid the bank, and offered one hundred and eight and a half dollars per share; that price making about twenty-seven thousand dollars more than the sum at which I had already bought the stock. This proposal of mine was approved by the Governor, and thus I became the purchaser of the stock a second time. And I have paid into the State Treasury a large portion of the price of it.

It may not be my province to judge whether the State, the Governor, or the bank gains enough by the means employed to extort twenty-seven thousand dollars from me to compensate for the use of such means. Being the sufferer, my judgment may not be free from bias.

If it be true, as you have been informed, that the bank has made two more bids since the stock has been sold to me the second time, one of $130 per share and one on the next day afterwards of $145 per share, it seems to indicate a remarkable advance in the value of the stock. From $81 per share offered by the bank on the 4th day of June, to $145 ten days afterwards, is an advance seldom witnessed outside of the oil regions. Under its temporary excitement the bank has perhaps gone on increasing its bid at the rate of $15 per day ever since the 14th, the day it offered $130 per share. This it could do with perfect safety, having doubtless learned the fact that my bid of $108.50 was confirmed the day before.

I am, however, gratified to know that my stock is so valuable, for certainly the bank should know its value better than any one else. But I cannot help fearing that its large offers are the result of a cheap effort to establish a reputation for liberality in its dealings with the State. If this effort had been made on the 4th of June, it would have carried responsibility with it. It would have merited and commanded success, and would have prevented this craving on the part of the public for information.

If the bank it really desirous of buying its stock at $145, my impression is that many of its private stockholders would be glad to sell at that price. It is equal to $89.25 cash per share. I notice sales of it made on 'Change yesterday at $66—under the hammer. Did the bank buy it? or does it intend to try and defeat the sale of it by tempting the seller with an offer of $89.25 before it is transferred?

The price I pay the State, $108.50 in bonds, is equal to the $66.77 per share in cash—just 77 cents per share more than the same stock brought yesterday at public auction. Comment is unnecessary.

Hoping the information I have given you is satisfactory so far as it goes, I will stop for the present. I have other information that may be given when I think it necessary.

JAS. B. EADS.

LETTER

TO HIS EXCELLENCY B. GRATZ BROWN, GOVERNOR OF MISSOURI, MARCH 21, 1871.

SIR,—I desire to place on file in the archives of the State this my solemn protest against the recent action of the General Assembly in the adjustment of matters growing out of the sale by the State to me of 10,863 shares of bank stock in 1866. And more especially do I desire to protest against whatever legality and moral force might otherwise attach to a certain letter dated March 17, 1871, written and addressed to Senator Spaunhorst, Chairman of Ways and Means Committee, and which on his motion was spread upon the records of the Senate. A similar protest was written by me on Saturday last, addressed to the President of the Senate, and forwarded to him for the purpose of having it spread upon the records of the Senate, but the early adjournment of that body on Monday prevented its timely reception.

I desire that this protest may be made a portion of the history of this remarkable transaction: first, that my self-respect may be vindicated by explaining the duress under which the letter in question was written; second, that the outrage upon the sovereign dignity of the State in thus forcing me to accept an unjust settlement, without the right to appeal by petition or otherwise to its justice, may be known by my fellow-citizens; and third, that the individual rights of others concerned may not be compromised by the said letter.

In thus protesting I have no intention to relieve myself of any disability under which I am individually placed, or of failing to abide by the terms of the letter in question so far as my own private rights are concerned.

I desire also to place on record my reasons for urging your Excellency not to veto the act as passed by the Assembly, the injustice of which was so apparently manifest as to cause you to hesitate to give the bill your sanction.

For more than two months I was, at great personal inconvenience, detained at the State capital in praying to recover either the property purchased or the price paid for it. During this time the most rigid investigation of the committees in the Senate and House, to which the subject was referred, failed to discover the slightest evidence of a want of good faith on my part throughout this entire transaction. The facts were developed before them as follows:

The sale should have been made on the 4th day of June, 1866. On that day I was the highest bidder, having offered $106 per share, payable in bonds of the State, which bid was duly reported by the agent to the Governor, and the verbal assurance given by the latter to me, in the presence of witnesses, that he would approve the sale to me, the market value of the stock being at the time from $65 to $66 per share. Afterwards a higher bid was made to the Governor, and the approval of the sale at $106 was refused to me. I therefore bid $108.50, or $27,000 more for the entire stock, and on the 13th day of June the sale was approved to me at that price. The law gave me thirty days within which to pay for the stock. Seventeen days after this approval, and after payment of $210,000 on account, a dividend of $104,410.17 was declared by the bank. This the State claimed. During the last March term of the Supreme Court this dividend was adjudged to belong to the State, for the sole reason that the sale on June 13 was informal, not having been made on the 4th of June, and was consequently absolutely void; the stock and dividend both being declared by the court to be the property of the State. On this decision the bank paid over the dividend to the State.

The fact was established, I believe, beyond question in the minds of every member of the two committees, that by law and usage the dividend belonged to the party owning the stock before it was declared. The Supreme Court adjudged it to belong to the State on the sole ground that she had not sold the stock.

These facts are nearly all, I believe, clearly enunciated in the preamble of the bill that is passed, and are consequently acknowledged by the State.

I assured the members of the committees, and of the Assembly, that I would be content to receive back what I had paid into the Treasury and restore everything I had received from the State, or to receive from the State everything which I supposed I had bought from her on the 13th of June, full payment of which, with over $13,000 besides of unallowed interest on my bonds, she had in possession. I assured these gentlemen that I would not consent to receive *less than all* I had *purchased*, or *less than all* I had *paid*, unless forced to do so.

The bill which has passed the Assembly and is now a law, in its first section directs the Auditor, as agent for the State, to sell this stock to me on the terms of my proposal, approved June 13, and it

declares "Said sale shall bear date June 13, 1866, and shall convey to said Eads the entire interest then in the State of Missouri as owner and trustee in said 10,863 shares of stock, and said transfer shall in all respects be in force and effect as if the same had been made on said 13th of June, 1866."

Section 3 of the bill, as reported by the House Committee, provided that payment of the dividend of $104,410 17 should be made to the bank from whom it was received, and by whom it would, of course, be paid to me and my assigns.

This section was stricken out of the bill in the House, and in this manner it was passed on Wednesday night. Appreciating the fact that by the non-action of the Assembly I was in danger of losing possession of the stock by the mandamus of the Supreme Court now pending for its recovery, and would thus be deprived of both stock and bonds, I urged my friends in the House to vote for the bill, believing that the dividend would surely be restored at the adjourned session; and for the same reason I urged its passage in the Senate. Many gentlemen when thus voting in both Houses explained that they did so to save me from greater wrong and embarrassment by the failure to pass any law whatever for my relief. The bill reported by the Senate Committee provided for a return of bonds paid by me, and not for a sale of the stock. Its consideration had been postponed from time to time, with the purpose of learning, first, what action would be taken by the House. At this time it was the special order for Thursday morning. It was, however, again postponed and made the special order for Friday morning.

The adjournment being fixed for Monday, I was admonished by the lateness of the session and the assurance of friends regarding the temper of the House, that any effort to pass a bill for the return of the bonds in it would be perfectly useless, as well as any attempt to amend the bill it had already passed.

On the opening of the Senate Friday morning I was served by Senator Spaunhorst with the following letter:

CITY OF JEFFERSON, March 17, 1871.

Jas. B. Eads, Esq.:

DEAR SIR—The Senate Committee on Ways and Means request your immediate answer to the following inquiries:

Will you accept the House Bill, No. 442, now in the Senate, as a settlement in full of the controversy now pending between yourself and the State, growing out of the purported sales of the bank stock?

Will you agree hereafter not to set up any demand, or present any claim against the State, or ask further legislation on the subject? Will you accept the bill referred to as a compromise, or final settlement, in the premises?

Respectfully,

(Signed) H. J. SPAUNHORST,
Chairman of the Committee.

It was intimated by him at the time that it would only be by

my consenting to answer these questions affirmatively that the committee would agree to pass the House bill.

To this letter I immediately wrote the following reply:

CITY OF JEFFERSON, March 17, 1871—10 A. M.

Senator Spaunhorst, Chairman of Committee of Ways and Means:

DEAR SIR—I have the honor to acknowledge the receipt at this moment of your letter, requesting an immediate answer to the questions propounded in it.

While I feel that great injustice is done me by the terms of the House bill, I nevertheless feel that it will protect me from the possibility of a greater wrong, in this: that when compelled to answer the mandamus of the Supreme Conrt within the next few weeks, I would have the alternative of availing myself of the provisions of the bill and retaining the property purchased, if the Court should rule that justice had been accorded me by the General Assembly. On the other hand, the lateness of the session and the advice of my friends assure me that any disagreement to the House bill at this time by the Senate will result in non-action by the Assembly, in which event I will in all probability be compelled by the decision of the Court to surrender the stock of the bank, and will thus be deprived of the thing purchased as well as the price paid for it.

Being completely in the power of the State, compelled to accept her award without the right to appeal to the Courts, if I deem myself wronged; your letter proposes that I shall also surrender the right of petition, which should be inalienable with the humblest citizen. If deprived of it I should be in duress, and any acceptance of your proposal would be void in law, questionable in morals, and an exaction contrary to the dignity of a sovereign State, and could only be consented to by me with a loss of my self-respect.

Your obedient servant,

JAMES B. EADS.

I also remonstrated verbally with the members of the committee, and explained that when the mandamus was acted on by the Court it might consider that equity had not been done by the Assembly, and might consequently let the matter rest *in statu quo* until the adjourned session, when the Assembly could then determine to restore the bonds or affirm the sale. That, by the provisions of the bill I would receive much less than some of the members of the committee had expressed their willingness to give me; and that by signing such a letter I would have to surrender all hope of future relief by the Assembly or the Supreme Court; besides this, it was a personal indignity to me to be compelled to accept such terms, when I and they knew that the bill did not accord me full justice; that the House had imposed no such terms upon me, and I did not know why the committee should. That they had no right to force a sale of the stock upon me, and keep back part of what I bought, because of any informality or irregular action on my part in making my last bid, as the State gained $27,000 by such informality; the doing of which was the sole result of bad faith and irregularity on the part of the Governor towards me. That if they were not willing to affirm the sale fully, they should restore my bonds.

These arguments failed to move the committee, and the further consideration of the matter was deferred until 7:30 P. M. In the mean time more than a majority of the members of the entire Senate promised to support the House bill without exacting this written obligation from me.

The Senate bill was the special order at 7:30 P. M., and a two-thirds vote was requisite to set it aside and take up the House bill. Every effort was made by the committee to prevent this from being done. The committee, consisting of five members, aided by Senators Buckland and Ittner, from St. Louis, and two or three members from the country, some of whom, I believe, opposed a sale of the stock on any terms, were under this rule able to defeat the views of the majority of the Senate, and by 10 P. M. effected a further postponement of the business until Saturday. My friends in the Senate now assured me that the attempt to obtain any legislation at this session for my relief, without submitting to this petty tyranny of the committee, was in their opinion utterly hopeless.

In addition to the interests appertaining to myself individually in this controversy, I felt the obligation imposed upon me as a Director in the bank to look after her welfare. I appreciated the fact that two-thirds of her stockholders had no pecuniary interests involved in the question of the dividend kept from me; and I knew that the probability of so large an amount of stock being thrown upon the market by the State had already greatly depressed the value of their stock, and must continue to work them perhaps greater injury, if this uncertainty was longer continued. I felt that these interests were paramount to the value of the $104,410 17, and I determined upon making the sacrifice. I accordingly, at 10:15 on Friday night, wrote the following letter, before referred to, and which appeared quite satisfactory to the members of the committee:

Senator Spaunhorst, Chairman of Committee of Ways and Means:

SIR,—I will accept House Bill No. 442 as a full and final settlement of all my claims growing out of the sale of bank stock to me by the State. Your obedient servant,

JAMES B. EADS.

At the time I wrote it I could not readily discover in my own mind any very striking difference between the justice and morality which dictated these terms to me and that which compels one to promise, when his wallet has been taken from him on the highway, that he will not prosecute for the recovery of his money, on condition that he be granted the luxury of retaining his clothes. Whatever differencc there may be I leave my fellow-citizens throughout the State to discover.

With great regard, your obedient servant,

JAMES B. EADS.

IRON BOATS AND BARGES.

LETTER

To Gen. Cyrus Bussey, Chairman of New Orleans Chamber of Commerce.

St. Louis, May 21, 1869.

Dear Sir,—I have the honor to acknowledge receipt of your invitation to attend the Commercial Convention, to meet on the 24th inst., in New Orleans. Fully sympathizing in the objects and purposes of the proposed Convention, and earnestly impressed with the necessity for concert of action by the people of the Mississippi Valley to advance, protect and assert their common interests, it is a matter of real regret to me that I am prevented by imperative professional engagements from accepting your complimentary invitation.

I must, however, avail myself of this opportunity to suggest to the Convention the importance of taking such steps as may be necessary to insure the success of the recent laudable movement inaugurated by some of the business men of St. Louis and New Orleans, and aided by those of the chief cities on the river; and with this view I beg respectfully to call the attention of the Convention to the importance of iron barges and iron steamers on the Mississippi River.

As these vessels are being used in all parts of the world, except in America, I would suggest that inquiry be set on foot by the Convention to discover why the grain growers and planters of this valley are not enjoying the advantages afforded by the introduction of such boats and barges upon the Mississippi. They are used upon all the chief rivers in Europe and Asia, several streams of which countries are far more rapid and dangerous than the Mississippi. Numbers of them are being constructed in Great Britain for the rivers of India, the Nile, the Danube, and, indeed, for streams in almost every quarter of the globe, save America.

These vessels will carry from ten to fifteen per cent. more cargo than wooden hulls of equal size, strength and draught, and never have their carrying capacity lessened by being water-soaked. They cannot be destroyed by fire, are made with water-tight compartments, and are almost absolutely proof against sinking. They do not require to be caulked after every trip, as wooden ones frequently do, and, being so much more tightly constructed, there is rarely any deduction to be made on their freight bills on account of damage to cargo. The plates of which they are made are frequently galvanized with tin at little expense, before riveting them together, and this preserves them without the cost of painting. They will last four or five times as long as the wooden ones, and when no longer useful for the purposes for which they were made, are still of considerable value for their old material.

With all these unquestionable advantages in their favor, why are they not used in America?

In England, barges of this kind are constructed for about two and a half pence per pound, but our tariff on iron makes them so costly to import, or to manufacture at home, that they are a forbidden luxury to the men who are tilling a valley of such marvelous fertility that they can contentedly see one argosy in every twenty destroyed by the flames or sunk by the sawyers of the Mississippi, for the sake of continuing for the next fifty years or so that protection and encouragement to our makers of iron that is ultimately destined to enable them to manufacture the material so cheaply that further protection will be unnecessary.

While our wooden vessels are destroyed by the half-score or half-dozen in a single conflagration, and hundreds of thousands of dollars vanish in the flames in an instant, it is idle to argue that transportation on our rivers is as cheap as it should be. I say nothing of the danger to human life, but view the subject as a money question alone. The destruction of steamers by a couple of fires of recent date—one at our own wharf and one at Cincinnati—would pay for the transportation of ten millions of bushels of wheat from St. Louis to New Orleans. I would ask those who are responsible for this state of things to point to any other country on the globe where such wholesale destruction of property occurs. Yet we claim to be the most enlightened people on the face of the earth.

If the gentlemen who have inaugurated this most laudable "Grain Movement" think they can make it a perfect success without cheapening the present cost of river transportation, they not only underestimate the cost to the shipper incurred by the present dangerous and expensive use of wooden vessels, but also the energy and ingenuity of their railroad competitors. Nature has given us, beyond all question, the cheapest medium for the transportation of the products of this valley, but we cannot reap the benefit of her lavish generosity

so long as we send our cargoes forth in tinder boxes and antiquated wooden tubs.

We are suffering under these great disadvantages that the manufacture of iron in this country may be encouraged through an indefinite period, until it can defy foreign competition without protection. Is it really encouraged by the duties now imposed? Is not this interest, after years and years of protection, now asking for higher duties? And has not this protection really operated to retard the development of that manufacture by the fact that the uncertainty of the continuance of the protection and the difficulty of estimating the real amount of advantage given under it, serve to lessen the ability of the capitalist to correctly estimate the actual advantages likely to be gained by an investment in its manufacture when the protection fails?

This may seem paradoxical, but I think it is not. Suppose, for instance, I require, say one million dollars worth of iron, and purchase it abroad, there will be paid into the treasury of the commonwealth several hundred thousands of dollars in duties, which will benefit every man, woman and child in the country, by enabling the nation to pay its debts and thus lessen its taxes; whereas, if purchased here, this amount, which represents the home manufacturer's profit, would go into his pocket alone, and its beneficial effects would consequently be very limited in extent. It may be asserted that in the latter case all the money would be kept in the country. It may be said in answer that by the foreign purchase the profit on the work (which is the most important part of it in a country where employment is abundant) would remain here and be equally distributed among the people, and that the entire amount that goes abroad in this way does not probably equal that which goes into foreign hands in the shape of freight money collected from our own people for carrying their own property in foreign-built ships through the effect of this miscalled protective system.

The enormous tax imposed upon the people of this great basin by the action of the present tariff, through its effect upon transportation alone, is not, I am sure, appreciated by them. On land, as well as on water, the onerous duty on iron impairs the prosperity and retards the progress of the great valley. Every portion of it, not immediately contiguous to one of the great rivers, needs a railway, and this duty taxes the building of a railroad about two thousand dollars per mile. The present tariff is, therefore, synonymous with high freights on land as well as on water. It curtails the extent and increases the cost of railroad facilities, binds us down to a dangerous and antiquated system of freightage on our rivers, and does not lose its blighting influence upon the commerce of the country, even after our wealth has reached the shores of the ocean, for it prevents our countrymen there from floating the protecting flag of their own land over

their own ships, unless they be built on American soil, and, as it costs them so much more to do this at home than it does their French, German and English competitors to build or buy them on the Clyde or the Thames, it forces into foreign bottoms the carrying trade of a people claiming to be the most enterprising and progressive of the age, and who certainly should be the most maritime in Christendom.

I think it is of the first importance that a Convention should be called to consider and examine into the effect exerted by the present tariff upon the industrial interests of the Valley of the Mississippi, and especially the influence it has upon our inland and ocean carrying trade. I hope the Convention will, at least, cause a committee of its most intelligent members to be appointed to report upon this subject, if it does not consider it a matter of such importance as to warrant a recommendation in favor of a Convention to consider the question.

Very respectfully, your obedient servant,

JAMES B. EADS.

[The communication was ordered to be spread at length upon the minutes of the Convention.]

IMPROVEMENT OF THE MISSISSIPPI.

ADDRESS

IN THE HALL OF THE ST. LOUIS MERCHANTS' EXCHANGE, JANUARY 30, 1878.

Mr. President and Gentlemen of the Exchange:

I propose to explain the causes of some of the phenomena and characteristics presented by the Mississippi River in the 1,300 miles of its pathway from St. Louis to the sea, and to suggest a system of improvement for this portion of it, so simple in plan and certain in effect that it cannot fail to commend itself to your judgment.

The laws which control the river are among the simplest of which we have knowledge, although the conditions affecting their operations are frequently so modified that its problems become very complex. Each portion to be improved, consequently, requires to be treated according to the different circumstances affecting it. One general system, however, will be found peculiarly applicable for the part flowing through the alluvial district, and it is this plan, as a whole, which I propose to explain. It is so simple that I can safely promise to each one who will give his close attention for a few moments to some of the seemingly dull explanations that I must make at the start, that he shall sufficiently understand the principles on which it rests to follow me step by step in their logical application to the deepening of the river and the lowering of its floods, until the grand fact that it is entirely within our power to thoroughly curb and guide its vast volume and prevent its distructive overflows, shall be fixed upon his mind as a conviction, scarcely less positive than that which daily assures him that the shades of night will vanish with the dawn.

First, let me call your attention to this horizontal line, which is intended to represent the level of the Gulf of Mexico. This other one, slanting upward from this end of the first, and rising steeper and steeper, represents the surface slope of the river in flood time. This point, the head of the passes twelve miles from the gulf, is three feet above its mean level. At New Orleans it is about sixteen feet; at Red River, fifty feet; at Natchez, sixty-six; at Gaines' landing, about half way to St. Louis, one hundred and forty-nine feet; at Memphis, two hundred and twenty-one; at Cairo, three hundred and twenty-two and at St. Louis, four hundred and twelve feet above the level of the gulf.

This line of flood slope fixes the height of the levees. So long as it remains at its present height, the levees must continue to be above it to protect the land. Any treatment of the river that will lower this line will tend to make levees unnecessary. If it can be lowered so as to be below the surface of the river banks, there will be no need of them.

Let me now direct your attention to the remarkable difference existing in the grade or inclination of this slope in various parts of the river. From New Orleans to the passes it is not an inch and a half per mile; from the passes to Red River, 300 miles, it is less than two inches per mile; but in the next sixty miles raises to 3 1-5 inches per mile, and gets steeper until from Memphis to Cairo it exceeds 5 inches per mile, and from Cairo to St. Louis it is over 6 inches.

The high-water mark at Cairo is 12 feet above the land; if this slope could be reduced from Red River to Cairo, 800 miles, only one-quarter of an inch per mile, it would lower the floods at Cairo 200 inches, or more than 16 feet! Yet, from Red River up, the slope suddenly rises in the first sixty miles from an inch and seven-eights to nearly three and a quarter. Thus it is here an inch and three-eights greater per mile above than it is below Red River. How can it be lowered? The current is the result of gravity, or of the falling of the water from a higher to a lower level; consequently the more rapid is the fall per mile, the greater is the force of gravity developed by any given boby of water. We see, then, that much more force must be developed by the water above Red River than below it, and, other things being equal, we should expect to find the current much more rapid above than below. But it is a remarkable fact that there is no very notable difference in the average velocity of the flood current from St. Louis to the Gulf. The reason of this is, that the river flows through a bed of its own making. What a sluggish current has deposited yesterday, or 5,000 years ago, a rapid current will take up to-day and carry onward to the sea. Hence the river, through its alluvial district, will not tolerate a current that is too rapid for its needs. No engineer can permanently maintain one in it, for if it be too rapid, it scours away the bed of the river, and as the bed deep-

ens, the slope falls and the current must slacken. And in like manner, no engineer can permanently slacken the current, for, if he slacken it, it becomes unable to sustain the load of sediment it carries. This is dropped in its channel, and the bed is elevated by the deposit, and as it is elevated, the slope is steepened, and the current must thereby be quickened again.

Gravity is the force impelling the water, while the friction of the bed is the chief element which retards it. Consequently when the water has most frictional resistance, it must have the steepest slope to overcome the resistance. This we will presently find to be the trouble above Red River.

Let me explain this matter of friction. If we have two water pipes, one a foot in diameter, and the other two feet, the frictional surface of one will be only twice as great as the other, but the larger pipe will hold four times the quantity of water per foot of its length, and consequently, if the two pipes have the same slope, the water will run most freely through the larger one, because the water in it has really only half the friction to retard it. So, to produce an equal velocity in both pipes, we must give the smaller one a steeper slope. This is precisely what the river does. When its grand volume is divided by islands, or expanded into great widths, the friction of the bed is increased, a sluggish current ensues, deposits are thrown down until the bed is raised, and if two inches per mile be not slope enough the depositing process continues until three or four, or all that is needed, is obtained. For, mark you, the river must have a certain rate of current. It will have it, and no man need waste his time in devising schemes to prevent it.

A certain rate of current is necessary for its very existence, as you will presently see; for its tributaries are annually pouring into its bed their burdens of sediment, and it must discharge this mud and sand into the sea or its own channels will become choked up. And it is equally important for it that the current be not too great, for it would then have its alluvial bed cut out, enlarged and unfitted for the purpose for which nature designed it.

We shall see that the Creator has, in His mysterious wisdom, endowed the grand old river with almost sentient faculties for its preservation. By these it is enabled to change, abandon or alter its devious channels, and elevate or lower its surface slopes, and so temper the force which impels its floods to the sea, that its currents may be regulated, accordingly as its needs are modified by the ever changing conditions with which it is surrounded.

The self-regulation of the current is accomplished by the power which nature gives to flowing water, to transport sand and earthy matters suspended in its volume. The river water is consequently charged with this solid matter, and its power to transport it depends wholly on its velocity.

This is, perhaps, the most essential truth underlying the plan of improvement I propose; and I want you to particularly note it, for it is boldly and persistently denied by Humphreys and Abbott and the army engineers who opposed the jetties at the mouth of the Mississippi. My convictions and theirs are diametrically opposed upon this proposition, namely, that the quantity of sediment carried in suspension by the river to the sea depends upon the velocity of the current. That is, that the quantity increases and diminishes with the velocity of the current, the ratio of quantity to velocity is, however, modified by the depth. That is to say, the quantity of sediment increases less rapidly with an increase of current in deep water than it does in shoal water.

Here is a plain, simple proposition, that the relation between the quantity of sediment suspended and the rate of current is an intimate and direct one. If I am wrong, the system I am proposing is utterly worthless, and the outlet theory of the levee commission, so emphatically indorsed by the Chief of Engineers, is correct. It will be seen, then, that the plan of improvement put before the country by the army engineers, and the one I propose, rest upon totally different assumptions regarding a fundamental physical fact, and therefore our plans are totally different. Mine is based upon the concentration and conservation of the river volume; theirs upon the theory that its diffusion by outlets will lower the flood-line; that changes in the velocity of the current do not cause its deposits to be thrown down in its bed, and that lessening the volume flowing through its bed will not lessen the channel nor steepen its slope. They declare that the results of long and carefully conducted experiments at Columbus and Carrollton, to determine this very question of relation between velocity of current and quantity of sediment, utterly disproves the existence of any such relation. My hopes of success at the jetties were based upon the fact that it does exist, as I have stated, and that the slightest check in the current will cause a deposit of sediment.

This pernicious error was advanced by Messrs. Humphreys and Abbot in their delta survey report seventeen years ago, and was reiterated by the chief of engineers during the pending of the jetty act. After its passage it was officially republished by him. More recently it has been again republished in the new edition of Humphrey's and Abbot's Report, with new arguments to support it. I therefore take this occasion to say that tables of results, of the Columbus and Carrolton experiments as published in Humphrey's and Abbot's Report do not sustain their statement, but do prove the proposition I have advanced, and I hold myself ready to prove before any committee of congress, or any competent scientific authority, and in the presence of either of them, that they have misinterpreted

their own data, and have thus been led into the publication of a grave scientific error.

This is a purely scientific question, but one of great moment in the problem we are discussing, and I think I can make you understand the error which these gentlemen have committed, by a simple illustration.

The grain trade in St. Louis has made most of you familiar with the elevators which handle it, and you have doubltess seen the little tin buckets attached to the vertical belt which travels around a pulley at the top of the elevator, and in which buckets the grain is carried upward. Suppose an engineer gravely told you that there was no relation between the velocity of the belt, or the power of the engine driving the belt, and the quantity or weight of the grain raised by it. Such a statement would be no less contrary to established physical laws that the error I am alluding to. But suppose the engineer reiterates his assertion and declares that long-continued investigation on his part proves the fact. You would still disbelieve a statement so contrary to common sense and daily observation, and would demand the proof. What would you think when he brought from his tables, and showed you that at one hour he found the speed of the belt was only 100 feet per minute, and the weight of the grain was sixty pounds per bushel, and at another time the speed was twice as great, while the weight of the grain was only forty-five pounds per bushel, and thereupon declared that there could be no relation between the power and the quantity raised? When you examined his tables, and found that he has given you the speed in all cases in one unit of time, say in one minute, but has failed to tell you what quantity or how many bushels were raised in that unit of time, but had given only the weight of a single measure in each instance, you would be disposed to tell him that he had better review the lessons he had received in natural philosophy, before attempting to generalize on such data. Now if you would take this data, and ascertain the total weight raised in each minute of time, and compare it with the speed or power during the same unit of time, you would see at once the direct relation between the speed per minute, and the total quantity raised per minute.

These gentlemen have made exactly such an error as this. They have given the speed of the current in feet per second, but have not given the total quantity of sediment carried per second, but only the weight of it in one cubic foot of water, in every instance, no matter whether the number of cubic feet per second was ten times as great in one case as in another. The volume of discharge is given in their report during the period of their investigations at Columbus and Carrollton, and by multiplying the number of grains given in a cubic foot by the total number of cubic feet discharged per second at each velocity observation, the relation will appear between the rate of

current and quantity of sediment carried, or between cause and effect. The graphical curves of velocity and sediment shown on their plate No. 12 in their report, show the speed per second of the current in feet, but do not show the quantity of sediment carried in each second by the river, but only that contained in one cubic foot of its discharge at the time of each velocity observation, therefore the two curves do not synchronize or correspond, and hence they have imagined that the relation between the two does not exist. This relation between velocity and quantity of sediment gave to the river its power to adjust its current so as to discharge only the average amount of sediment annually poured into it by its tributaries. Outlets inevitably tend to increase its slope and elevate its bed. He explained also how the wide places, by disturbing the regularity of the current produced the caving banks, the shoals and the cut-offs; and said that the levee system, as proposed, only tended to perpetuate these evils. A uniformity of width of the river was the only means of curing these evils, and this would at the same time deepen its channel and lower its floods. It was *a strictly high water treatment*, and if adopted deep water would be secured throughout the low water seasons. No cut-offs nor straightening of the river was suggested, nor would any be needed. The levees can be ultimately dispensed with, and there is no need of doing anything more with them now than to repair the crevasses, and raise the levees to the same condition that they were in before the war.

The river improvement should be commenced at once. You have no time to lose. Forty-three bars are known to exist below Cairo, by the government survey of 1875, and some of them with but four and one-half feet of water on them.

It will cost possibly $50,000,000 to improve the river below Cairo. This would secure at least twenty feet through to New Orleans in low water. I will not attempt to speak of what this would be worth to this nation. No eloquence of tongue or pen can picture it.

The St. Louis Merchants' Exchange was the first commercial body to move effectually in the opening of the mouth of the river, through its emphatic endorsement of the jetty system, and one of its most honored and influential members, Hon. E. O. Stanard, then in Congress, gave it his earnest and able support, and, I believe, saved the bill at one of the most critical moments of its existence. The present measure is one of far greater importance to the prosperity of St. Louis, the whole valley and the entire nation than the opening of the mouth of the river. With twenty feet from hence to the sea all the year round, grain can be profitably carried to New Orleans for three cents per bushel. The North and the West can estimate what it would be worth to them on grain alone; but no man is competent to picture he prosperity of the whole valley when this improvement shall have

been once accomplished. I trust, therefore, that the Exchange will move vigorously in securing so grand a consummation.

Webb M. Samuel offered the following resolutions, which were unanimously adopted:

Resolved, That the Board of Directors of the Exchange be requested to take such action in reference to the plan of Mr. J. B. Eads for the improvement of the Mississippi River as will bring the subject prominently before Congress and the people of the Mississippi Valley; and that the thanks of the merchants and business men of St. Louis are justly due and are hereby tendered Mr. Eads for the great work performed by him in opening the mouth of the Mississippi to the commerce of the world, and also for the efforts he is now making to give to the commerce of St. Louis and the Mississippi Valley an unobstructed and deep-water outlet to the jetties.

ADDRESS

Before the Cotton Exchange of New Orleans, Feb. 15, 1878.

Mr. President and Gentlemen:

In response to your wish, I shall endeavor to explain some of the peculiar phenomena that are observed in all sediment-bearing streams when flowing through alluvial districts, and shall try to make you familiar with the causes of these phenomena, so as to enable you to judge correctly as to the merits of the system of improvement which I am urging for that part of the river which lies between St. Louis and the sea.

I shall be compelled to ask your close attention to these preliminary explanations, for although they will appear dry and uninteresting, they are absolutely necessary to insure a correct understanding of the subject. I am sure that when you reflect upon the magnitude of the benefits that can certainly be secured to each and every calling and avocation pursued by the twenty million people who inhabit the grand empire whose concentrated rivulets and streams flow by your favored city in such majestic volume, that you will consent to listen patiently and without prejudice to a system of improvement designed to secure the speediest and most permanent possible benefits to the people who occupy the rich alluvial basin of the river, and

to the producers and consumers of the products of the seventeen States that constitute the Valley of the Mississippi.

This plan is the result of much thought and a long and intimate knowledge of the river, and as I have no intention of proposing to make any contract or secure any concession from Congress for the execution of the work, and am not anxious even to undertake the direction of it, I can assure you that I have no more selfish motive in the matter than the ambition to benefit my fellow-men. I will add, however, that having aided to secure, through the unwavering faith and substantial aid of others, a deep and permanent outlet to the sea for the grand old river, I intend to devote all the energy and talent that God will give me to secure such a system of improvement for the whole stream as will make it in the highest degree useful for the varied wants of my countrymen.

To this end I shall oppose with tongue and pen every attempt to institute a defective or improper method of improvement for it, and shall not cease to expose the errors and false reasoning of those who, disregarding the natural laws which control it, propose methods which my judgment assures me are radically wrong.

And inasmuch as I have been charged in a recent official letter, published by the chairman of the St. Paul Convention, with hostility to the engineer corps of the army, it is proper that I should warn you against the persistent efforts of the friends of the outlet theory to induce the public to believe that I am making war upon the United States Engineer Corps simply because I oppose with all my might some of the dangerous errors which were advanced by Messrs. Humphreys and Abbott seventeen years ago in the delta survey report, and which have been adopted by a portion of the corps, and which form the basis upon which the majority report on the Fort St. Philip Canal rests, and that also of the United States Levee Commission. This is simply a ruse to make the public believe that the theories and conclusions of the Humphreys school of engineers are those of the entire corps. It is very unjust to class in that school such engineers as Barnard, Wright, Alexander, Comstock, Merrill, and others of the corps who never opposed the system which has given to your commerce a deep passage to the ocean, and who have never adopted the theory that alluvial channels will not become smaller and steeper by reducing the water flowing in them, and that crevasses and outlets will permanently lower the flood-line of the river, and that the river is not flowing through a bed of its own deposits. On the contrary, Gen. Barnard was the sole member who dissented from the views of the Fort St. Philip Canal Board, of which he was president, and who declared the jetty system practical, using, in 1874, the memorable words, "The time will speedily come when the people's cry for a navigation unimpeded by locks—AN OPEN RIVER MOUTH—will be heard." And even as early as 1852 Gen. Barnard,

with Gens. Beauregard and Chase, all members of the corps, recommended the trial of jetties at the mouth of the river.

Gens. Wright, Alexander, and Comstock were members of the board which declared in favor of the jetties, and although Gen. Wright gave the preference to the canal, it was not because he believed the jetty system impracticable, but because he believed the other the more certain of the two; and I believe none of the other three officers are more rejoiced at the success which has attended the jetties than he is, because a great question in river hydraulics has been settled with advantage to the nation. While these officers, who were appointed by the President upon the board, gave their judgment in favor of the jetties, the chief of the corps, who controls its operations and thus fixes its standard of value in the public estimation, continued, even after the law was passed, to publish, at the expense of the Government, erroneous arguments calculated to lessen the value of the conclusions of the commission and to create public distrust in the efforts of myself and associates, and thus added to the legitimate difficulties surrounding our efforts, those of petty official interference. It is wrong and unfair to charge me with making war upon the engineer corps, when so many of its members, by their virtues, their talents, and their patriotism, command my respect, and are deserving of that of their country.

Craving your pardon for occupying your attention so long with this personal explanation, I will proceed to explain some of the phenomena of the river.

The speaker then referred to the diagrams illustrating his remarks, and called attention to the fact that the surface slope of the river in flood time increases gradually as we ascend the river from the head of the passes, being less than an inch and a half per mile below New Orleans, and only one and seven eighths of an inch at Red River, while in the next sixty miles it rises to nearly three and a quarter inches, or nearly double the grade. This rapid increase becomes still greater as we proceed on up, until at Cairo it exceeds five inches per mile, and is over six at St. Louis. He said:

Particular attention is called to this question of flood slope, for this is really the levee question. If the slope were steeper, the levees would have to be higher, because they must be above this slope to prevent overflows. Hence everything tending to alter the slope of the river should be of deep interest to those who are directly interested in the levees.

The current is the result of the fall of the water from a higher to a lower level, and the inclination of slope of course indicates the force which the water is exerting. Now, the steeper is the slope, the more rapid we ought to expect the current to be, but we find there is really but little difference between its average velocity here, where the slope is least, and at Cairo, where it is so great.

The current is retarded by several causes, but the grand and chief one, and the only we need consider to-night, is that of the friction of the water in passing through its bed. The ratio of friction rapidly increases as the volume or quantity of water flowing, is reduced, because then the proportion of water in contact with the surface is is greater. This may be illustrated by supposing two water pipes, one of one foot and the other two feet diameter. The circumference of the large pipe being twice as great as the other the water in it will have twice the friction of the small one, if both be placed at the same inclination, but we will find that the water in the large one flows much more rapidly than in the other, because while the friction is only doubled by the diameter, the volume has been quadrupled, so that the water in it has really only half as much friction to retard it as that in the small one. Hence, if we want the same velocity in the small one, we must give it a steeper slope, or greater head. The river does this and we must naturally expect its slope to steepen as we proceed up stream, because the volume is diminished above each tributary, and because of the laws which control falling bodies. But we find that this does not account for the enormous increase above Red River, and hence we must look for another cause for it. As it is the surface of bed in contract with the water which creates the friction, it follows that if the bed be narrow and deep, the friction will be much less than if the width be great; and if, as is the case in many places, the width be four of five times greater than at others we must expect steeper slopes than where it flows in the narrow channels. Above Red River up to Cairo and above there we find there is one continued succession of wide places. Islands also increase the slope just as we should have to increase the slope of the water in our two foot pipe, if we divided it into two streams as an island divides the volume of the river, and here the islands are numerous.

We know that the channel of the river from Red River to Cario is continually shifting, and that violent changes are made in its location by cut-offs, so that these slopes must be also suddenly altered. Then why is it that the average rate of current is restored despite these changes?

This inquiry brings us to another part of our subject, and when you fully understand it, you will see that nature has endowed the river with something wonderfully resembling the instinct of self-preservation that is common to the animal kingdom.

The adjustment of slope so as to regulate the current results from the sediment bearing quality possessed by all water when in motion. The great mass of earthly matter continually carried by the river to the sea, is borne in suspension by the water, and the quantity with which the river is charged is determined by the velocity. If this be reduced, a portion of the sediment falls. If it be stopped, and the water be still, all of the sediment falls to the

bottom. If the bottom be of sedimentary matter that has not been changed by time into stone, then an acceleration of current at any place will cause the water to take up from the bed such additional quantity of sediment as may be due to an increase of velocity.

The river is flowing over a bed of its own deposits from Cario to the sea, and sediment thrown down in it yesterday, or a thousand years ago, is readily taken up again to-day if the current be accelerated over it. This fact is proven by every cut-off that has ever been made on the river.

A little thought teaches that the quantity of sediment annually discharged into the Gulf and over the banks of the river, through any long period of years, must be very nearly equal to the quantity discharged into it by its tributaries; for if it were less, the bed would be built up and elevated by the quantity left in it and the slopes steepened, and if it were more the bed would be deepened, the slope lowered and the current finally destroyed. We may then properly call that rate of current the normal one which carries the sediment without loss or gain. If from any cause, a cut-off for instance, the normal velocity be disturbed, the river at once goes to work to restore the disturbance in the current. Above the cut-off the current has been suddenly accelerated and rushes rapidly through the new channel, and geathers up from its bed in and above the cut the extra amount of sediment due to this increased velocity, while below the cut the opposite conditions exist. The surface there is quickly raised by the rapid drain going on above; the current is then less rapid than before, and the excess of sediment falls to the bottom, and these effects are produced up and down below the cut as far as the disturbance is felt.

If a flood occurs the water acquires a high velocity in the narrow parts of the river, and corresponding quantity of sediment. This current cannot be maintained through the wide places, and therefore the sediment falls in the bed in them until the bottom is raised and a steeper slope and higher velocity are created by the effort of the river to maintain the normal velocity, which is that rate that will discharge all the sediment poured in by the tributaries without gain or loss. But when the flood falls we find these wide places filled up with deposits and covered with sunken stumps and logs, through which the low water channels are cut.

Evidently, then, a uniformity of width must produce a uniformity of depth, and this in turn insures a uniformity of velocity. This insures a uniform charge of sediment, and as the tributaries determine the quantity, and a given velocity will only sustain a proportionate quantity of sediment it is plain that there will be little or no depositing or deepening of the bed. This explains why below Red River caving banks occur to such a limited extent, and why they are so devastating above. Bring the high waterchannel to an

approximate uniformity of width and the caving of the banks will be reduced to insignificant proportions.

You will now comprehend why the levee system must ultimately be abandoned, simply because it requires these wide places, the fruitful and only cause of caving banks and cut-offs to be inclosed within the levee, and hence the caving and the cut-offs must continue and the destruction of the levees must follow. You will ask why cannot the caving be prevented by rip-rap or mattressing the banks? The answer is: this may be done on the Po, the Rhine, or the Wabash, at some moderate cost, but the Mississippi is too vast in its volume to admit of it with any amount that would be voted by Congress as a palliative measure. You would have to stop the excavatious of the river where its forces are working a hundred feet beneath the surface.

Narrowing the wide places is a thing much easier accomplished, because it needs no work done except in shoal water. Where it is deep it is already narrow.

The steep flood slopes which we find even in the narrow parts of the river above Red River, and in the Atchafalaya Pass and in every outlet and bayou of the river, and in the island chutes, should teach every thoughtful person, it seems to me, that one universal law controls the channels in the alluvial district, which law demands that where the volume is reduced the slope must be steepened, and therefore if we would lower the levees we must not lessen the volume. I am satisfied that if the volume below Red River were increased, as it would be by closing Atchafalaya and compelling Red River to seek the sea by way of your city, it would lower the flood line five or six feet at the mouth of Red River and more than two feet at New Orleans.

The same reasoning assures me that closing all gaps and crevasses in the levees and thus increasing the volume in the natural channel will not necessitate higher levees, and hence the estimate of $46,000,-000 is very excessive and uureliable, because it is based on the idea of raising them from three to eleven feet higher than before the war. The great objection to the levee system is not from the present amount needed for absolute protection from the near floods, because four or five million dollars would insure this; but it is the incessant destruction of them which must ensue from the cause I have named. Remove that cause and the levees can be cheaply maintained, but when the cause of the caving banks is removed we will find the flood slope lowered and levees useless.

It will be seen that the system is radically different from that advocated by the Levee Commission, by Humphreys, Abbot, Warren, Hebert, and engineers of lesser fame, who adopt the theory that there is no relation between the velocity of current and the amount of sediment carried; because they have invariably compared the velocity per second with the sediment contained in a cubic foot of

water, and not with the total amount carried by the whole river in each respective second of time that the velocity is noted.

They advocate the diffusion of water by outlets and raising high levees around the wide places. I advocate its conservation, every drop of it, in one channel of uniform width, and the abolition of all the wide places; the closure of the outlets, every one of them, and, if found necessary, the closure of the island chutes. They propose to attack the banks of the river with shovel and wheelbarrow, to accommodate its anticipated elevation ten or a dozen feet higher than ever before. I propose to set the river to work in the bottom of its bed, as we did at the jetties, and, while deepening it for the benefit of commerce, lower its haughty crest forever. They provide for a river carried threateningly above the land, a constant source of terror and anxiety, while I propose that its vast volume, in all the grandeur of its mightest floods, shall be viewed with an admiration devoid of fear, from happy homes safe above its surface.

REMARKS,

AT A MEETING OF CITIZENS IN THE HALL OF THE ST. LOUIS MERCHANTS' EXCHANGE, OCTOBER 1, 1883, IN HONOR OF THE MEMORY OF COL. GEORGE KNAPP, SENIOR PROPRIETOR OF THE MISSOURI REPUBLICAN.

MR. PRESIDENT: I gladly avail myself of this opportunity to lay the poor but heartfelt tribute of my praise upon the alter of our deceased friend. I witnessed yesterday the deep and universal sorrow which marked the countenances of the vast multitude who followed him to the grave, and I thought that if there chanced to be one witness of the scene to whom the name and fame of the honored dead were unknown, he would need no other assurance than this that a great and good man was being borne to his final resting-place, and that his friends and admirers embraced the entire scope of society, from the humblest member to the most exalted in the State.

It has been my great good fortune to know George Knapp, as boy and man, for the long period of half a century. During the last twenty-five years my acquaintance with him has been intimate, and our friendship, which had its birth many years before, has never, so far as I can remember, had the slightest interruption up to the day when, accompanied by one of his loving sons and a devoted daughter, I took him, worn, weak and exhausted with overwork, to the steamer, which carried him a few months ago from the land of his birth never to return alive. I have sat with him at the council board when the policy and programme of some of the greatest undertakings in the State were mapped out and determined. I have been his partner in several important enterprises looking to the public welfare; have enjoyed his hospitality; have seen him under sore financial trial, irrited by the attacks of his enemies, and again in the high tide of success; in fact, under all the various influences, temptations and phases which attend men of great mark; but in all these varying circumstances I never heard George Knapp utter or favor an unjust, ungenerous or dishonorable sentiment. He was the very idol of his wife and children, a true friend and a fearless defender of the right. His love for his fellow-men as a class seemed unbounded.

> "Through all the compass of the notes it ran,
> The diapason closing full in man."

It was this high impulse which caused him to aid to the utmost of his financial ability the various railroads which are developing the resources and weaith of the State. The bridge which spans the Missouri at St. Charles; the one in front of our city, over which passes the commerce of a continent; the jetties at the mouth of the Mississippi, which are said by careful statisticians to effect a saving to the people of the valley of the Mississippi of at least $100,000,000 annually—all stand to-day as mute but splendid monuments to the philanthropic sagacity of George Knapp. Not only did the columns of his paper teem with strong arguments in favor of these great works, and others of lesser note which adorn our city, such as the Southern Hotel and the Republican Building, but into each and all were put with lavish hand the hard earnings of him who now lies so peacefully in Bellefontaine. This commercial palace, this Chamber of Commerce, the grandest of all the noble structures which embellish our city, owes its very existence to the indomitable energy and matured mind of the modest little boy who carried the *Missouri Republican* nearly sixty years ago to its patrons in St. Louis. What a noble record! Even death cannot deprive us of the good and useful influences which the life of George Knapp leaves to posterity. His history will forever breathe hope to many an humble aspirant, and point the way of the disheartened toiler to prosperity and eminence.

INQUIRY

And Report Upon the Bar and Estuary of the Mersey.

London, March 31, 1884.

A. T. Squarey, Esq., Solicitor to the Mersey Docks and Harbour Board:

Dear Sir,—I have the honor to submit the following report in compliance with the request, contained in your letter of the 21st of February, 1884, in behalf of the Mersey Docks and Harbour Board, to examine into and report upon the physical conditions of the estuary of the Mersey, in relation to the maintenance of the access to the docks on both sides of the river; of the channels connecting the estuary with the sea; and of the bar, including the results which will probably follow the construction of the works proposed to be built in the estuary by the Manchester Ship Canal promoters.

Very sincerely yours,

Jas. B. Eads.

REPORT.

The physical characteristics of the Estuary and Bar have been so fully presented in the last report of Captain Graham H. Hills, R. N. Marine Surveyor, that it will be unnecessary for to me describe them here.

The tendency of all estuaries of the sea is to lessen their tidal capacity through the more or less rapid operations of nature, acting upon the solid material which the land drainage and the oscillations of the sea bring into them. My investigations satisfy me that the estuary of the Mersey is no exception to the rule.

A comparison of the survey of Captain Hills with that of Fearson & Eyes, in 1735, and with that of Giles, made in 1819, and with Denham's in 1833, gives undoubted evidence of a decrease in the tidal capacity of the estuary, and of an extension of the crest of the bar into the Irish sea. The outer contour lines of the deepest channel, as it existed in 1833 were about two thousand yards nearer inland than they are to-day; thus clearly showing an advance of the crest of bar at an average rate of 120 feet per annum during the last

fifty years. The channel as reported by Captain Hills at the present time, is about 9 feet deep at low water spring tides, which is 3 feet less than that shown on the survey of 1819.

The depth in the several channels over the bar is maintained by the outward currents which flow through them, caused by the discharge of the water from the estuary. As the force of these currents must depend upon the quantity of water discharged, and as but a small portion of this is contributed by the rivers emptying into the estuary, it follows that the average size of these channels must be almost wholly determined by the quantity of sea water which the estuary is capable of receiving at each tide, or in other words, upon the capacity of its tidal basin.

Although the difference in the depth to-day in the main channel is strikingly less than it was in the year 1819, this fact alone would not prove that the shoaling is due to a diminution in the tidal capacity of the estuary during that period; but, when taken in connection with the evident advance of the crest of the bar, the two facts leave no room to doubt that the reduction in depth is due to that cause. A loss of tidal capacity alone would cause the crest of the bar to come farther inland as well as to shoal. The river drainage silt has prevented the retreat of the crest due to loss of tidal basin, but not the loss of depth. This latter can only be prevented by keeping the tidal basin unimpaired. Fluctuations in the depth of the channel may occur from time to time, from causes not directly connected with the tidal capacity of the estuary. Such changes frequently occur from the translatory action of the waves of the sea under the influence of exceptional storms or winds. When some of the minor channels are thus enlarged or diminished, an opposite effect in the main channel will result. But such changes would be but temporary, and would not be followed with any permanent advance of the bar. Any considerable disturbance of the equilibrium between the gravity of the sand and the force of the current, indicated by a decided shoaling or deepening of the channel, after a severe storm, might require a month or two to re-establish the old regimen or condition, for such disturbances are, like the vibrations of the pendulum, much more energetic during the first period than the last. The loss of depth and advance of the bar during this fifty years, I think, is undoubtedly due to a gradual loss of tidal capacity, and to the silt resulting from the land drainage. The rate at which this loss is progressing, so far as I am able to judge from a comparison of the surveys, is not such as to threaten any serious injury in the near future, if the natural processes by which it is caused, be not promoted by injudiciously tampering with the estuary.

So far as I have been able to discover, I find no reason to think that the depth on the bar, or the access to the docks at Liverpool and Birkenhead, or the stability of the channel between the sea and the

estuary, are in any immediate danger of impairment from any of the natural conditions with which they are surrounded.

Undoubtedly the greatest danger to these immensely important adjuncts to the commerce of Liverpool and Great Britain, lies in the proposition now pending before Parliament, to construct certain works in the estuary between Astmoor Marsh and Garston, to which you have called my attention.

In answer to this part of the inquiry with which you have charged me, I beg to state that I have examined the general plan of proposed works in the estuary, as shown upon the chart of the Parliamentary plan of the Manchester canal promoters for 1884, and have examined the part of the estuary in which the proposed works are to be constructed.

I have also read the testimony of Mr. E. Leader Williams, engineer and projector of the proposed canal, given before a committee of the House of Commons last year, in explanation and defence of his plans. I have likewise examined the different surveys of the estuary and bar, and the depths shown on them, from the deep water of the Irish sea to the point where the ship canal is to enter the Astmoor Marsh, and as I feel certain that the construction of the proposed works in the estuary, will seriously affect the present depth of water over the Mersey bar, and endanger the access to the Liverpool docks and to those of other localities in the estuary; and inasmuch as I differ in opinion with several distinguished engineers upon this important subject, and would not willingly create an unjust prejudice against a project which has doutless occupied, for several years, the profound study of the accomplished projector of the work; I shall endeavor to make the basis of my reasons for this adverse opinion so plain that any one may be able to form a correct judgment regarding the soundness of my conclusions. To do this, however, it will be necessary to state certain simple truths, which will, doubtless, seem very commonplace; but, if these are remembered as we proceed, it will be in the power of any one comprehending them to understand the cause of the various phenomena presented by the bar and estuary of the Mersey, and to form for himself a correct judgment in the premises.

First.—Currents in water are primarily created by the force of gravity.

Second.—The resistance to the current is almost wholly due to the friction of the bed over which it flows. Hence, gravity and friction being the chief controlling forces, and acting in opposition to each other, have such an overmastering influence upon the phenomena of rivers and harbors that in the problem we are considering we may, at least for the present, omit any reference to the minor elements which tend to modify their relation to each other.

Third.—The velocity depends upon the volume of water, the height

from which it falls in a given time, and the frictional resistance of the bed over which it has to move during that time.*

Fourth. — The inclination of the *surface* of the water (not the slope of the bed) is the measure of the height through which it falls in any given unit of time.

Fifth. — The friction of water differs from that of solids. It is not increased by the weight of the water, but it seems, from all experiments of which I have knowledge, to increase and diminish in exact proportion as the surface of the bed in contact with the water is increased or diminished, provided the general character of the surface in contact be the same. That is to say that, while it will flow with less friction in smooth pipes than in rough ones, it will increase or diminish its velocity in proportion as the wetted perimeter of either is increased or diminished. Hence the velocity of streams with the same volume and the same slope of surface, will be more rapid through deep channels than over shallow ones.

I desire particularly to emphasize the importance which attaches to the element of friction in the present inquiry; for I think the majority of engineers in the study of problems like the present, too frequently overlook it. It would be as unwise, I think, to ignore its consideration, in this investigation, as it would be, when designing a steam engine, to fail to take into consideration the resistance to be overcome, or the work to be done by the engine.

From the last axiom stated it is plain that the *velocity* of a stream, without increasing either its volume or its slope of surface, may be increased or diminished by simply increasing or diminishing the width of its bed. The fact that a river flows faster, generally, through its deep channels than its shallow ones, is so well known that it seems useless to refer to it; but the extent to which the current is modified by the increase or diminution of the frictional area over which the water flows is not so well known. Its importance will be seen as we proceed.

Perhaps one of the most notable illustrations that can be given of the influence of the friction of water is to be found in the fact that a pipe with a given inclination will discharge a larger quantity when it is partly full than if it be wholly full. Thus, the water flowing in a pipe 2 feet in diameter, with a fall of one foot in twelve, will be found to attain its maximum discharge when the depth in it is about 22½ inches, or 1½ inches less than when it is full. The reason of this is that the additional 1½ inch of the upper portion of the circle, adds but a small quantity to the volume, but it brings a large additional surface of the pipe into contact with the water.

* I do not here refer to currents caused by momentum (or the weight and velocity of the water), by which it is made to rise sometimes to a higher level than that from which it fell.

Sixth.—A considerable part of the force developed by flowing water is expended in transporting solid matter either *on the bed or suspended* mechanically in the water, but generally in both ways. Currents flowing over alluvial or sandy beds carry in *suspension* much the larger part of the material transported.

Seventh.—The quantity of solid matter which the water transports is immediately increased or diminished with every increase or diminution of current velocity, where the water flows over sedimentary deposits. The fact that this very sensitive relation does exist between the *velocity* of the current and the *quantity* of the matter transported by it, is one of the very highest importance in the present inquiry, and for this reason I will be pardoned for going into this part of the subject at considerable length. Its importance will be fully recognized before the inquiry is closed.

Observations have been carefully made upon the Mississippi river which demonstrate, beyond the possibility of doubt, that the slightest diminution of the current suffices to cause it to deposit a portion of its burden, and, conversely, that the slightest acceleration causes it to to increase it. The most incontrovertible evidence of this fact can be adduced by the results of works constructed at the mouth of the Mississippi river, in the river itself, and in the Missouri river.

The existence of such direct relation between the *velocity* of the current and the *quantity* of suspended matter, has been doubted by many distinguished engineers, and was stoutly denied by Humphreys and Abbot, two well known engineer officers appointed by the United States government, about twenty-five years ago, to make a careful survey and report upon the alluvial basin of the Mississippi river. General Humphreys was afterwards Chief of the United States Corps of Army Engineers.

The existence of this relation ten years ago constituted the main question at issue in forecasting the probable results which would follow the application of jetties at the mouth of the Mississippi river. Up to that period all the harbour and river works of the United States were in charge of the Engineer Corps of the Army; and it was held by all of its members who gave public expression to their opinions at the time, upon this subject, that no such relation existed. In the voluminous and elaborate report of Humphreys & Abbot, they declared that the result of careful experiments made to determine this question, occupying several years, at two points on the river one thousand miles apart, totally disproved its existence. Their report was extensively copied, and was translated and republished in several European languages, and for years was considered very high authority upon river hydraulics. During the discussion relating to the improvement of the mouth of the Mississippi, an article published in Van Nostrand's *Engineering Magazine* by me, in 1878, clearly pointed

out the error they had fallen into, in coming to this conclusion. The tabulated results of their own experiments were taken, and by them, the actual existence of the relation in question was fully proved. The denial of such relation is in direct conflict with the most elementary laws of physics, for, inasmuch as there must be a relation between cause and effect, it follows, as a corollary, that there must be relation between the *quantity* of the cause and the *quantity* of the effect. The current being, undoubtedly, the cause of the suspension of the sediment, the quantity suspended must bear a direct relation to the quantity of force expended in suspending it. In the article referred to, it was maintained that, without the expenditure of force, this heavy matter could not be held up in the water or transported by it, and that if any portion of the force thus being expended by the river, were absorbed in the slightest degree, even by the turning of a mill-wheel, or by the friction of a fish net stretched across the current, a proportionate deposit of sediment must follow. Shortly after this proposition appeared in print, nettings of wire with very large meshes were placed, by the United States Engineer officer in charge of the improvement of the Missouri river, across its current in one of the wide places in which the channel was to be contracted. The upper edges of these screens were buoyed with empty barrels, and the lower ones anchored to the bottom with bags of stone, so that the screens were held in a nearly vertical position. The consequence was that in one season of flood a deposit of 16 feet in depth resulted from the absorption, by the friction of the netting, of a part of the force which was being expended in transporting the sediment.

The intimate relation between the velocity and sediment has, in this inquiry, a no less important bearing, in proportion to the interests involved, than it had in the United States in respect, not simply of the question of the proper method of improving the only natural outlet for the commerce of the Mississippi valley, a territory about fifteen times as large as France, but also in its bearing upon the plan to be adopted for the improvement of the channel of thirteen hundred miles of the river, and likewise with respect of the proper method of protecting from inundation an exceptionally fertile territory, on each side of the river, three times as large as the alluvial basin of the Nile.

It was held by Humphreys & Abbot that the quantity of sediment carried in suspension was very variable, and followed no law; that the feeblest currents were sometimes found to be charged with the greatest quantity of sediment, and that therefore no deposits in the channel would occur from such loss of velocity as happens in the river when a portion of its flood escapes through crevasses or outlets, and thus finds another route to the sea. It was pointed out to them, that shoals were known to exist below some of the most

noted crevasses; but they declared that none of these were caused by a crevasse; and as no surveys of these localities had then been made, it was impossible to disprove their assertion at that time. The most noted of these shoals at Bonnet Carre, they asserted, was composed of an ancient blue clay which the current could not erode, and that careful examinations had been made by them throughout the whole alluvial basin, which proved that the bed over which the Mississippi flowed, was composed of this clay into which the current could not penetrate, and therefore, that the only way of confining the enormous floods within the levees, was by raising these embankments to a height corresponding directly with the amount of waters to be retained within them.

In 1874 a commission of five engineers was authorized by Congress to prepare estimates and report upon the best means of protecting the alluvial basin against overflow. This commission strongly endorsed these erroneous views, and actually recommended raising the levees accordingly, between Cairo and New Orleans, a distance of a thousand miles, at a cost estimated by them at nearly forty-six million dollars. A strong party, both in and out of Congress, believing in these errors, advocated what was known as the "*outlet* system," by which the floods were to be reduced in height by allowing a large portion of them to escape through natural and artificial outlets. In opposition to this were ranged the advocates of an exactly converse treatment, which was called the "*Jetty* system," from the works at the mouth of the river. As the works there gradually served to prove the remarkable synchronism, between the variations of the current and the deposit, the "Jetty system" grew in favor.

Finally (in 1879) a commission, consisting of six engineers and one civilian member was constituted by Act of Congress to mature a plan of improvement for the river, and to investigate and report upon the three systems known as the "Jetty system," the "Levee system" and the "Outlet system." This commission recommeded to the Government the adoption of the "Jetty system." Careful surveys and a system of precise levels were immediately commenced by the commission throughout eleven hundred miles of the river. Borings were also made at a great many different localities throughout this distance, to determine the correctness of the assumption that the river was flowing over a stratum of clay which would not yield to the action of the current. This assumption was declared by the commission, in its second report, to be totally unfounded. In its fourth report, (1884, of which I have, as yet, received only a newspaper copy), it is stated as follows:

"To ascertain the effects of the outlets, particularly in the form of crevasses, resurveys have been made in the neighbourhood of several of the great breaks of 1882, to compare these with the general survey

which was extended over the river in the year 1880 and 1881. In every observed case large loss of section occurred as follows:

At Malone's..................	2,200 square feet, or 4 per cent.
At Riverton	1,100 square feet, or 14 per cent.
At Bolivar....................	8,400 square feet, or 11 per cent.
Mount place................	23,800 square feet, or 24 per cent.

"The above figures are the mean of numerous lines run at each place.

* * * * * * * * *

"Similar observations have been made during the year at Bonnet Carré, with the difference that the foregoing comparisons were between channels before and after the breaking of the crevasses, while the following is between a channel during the flow of a crevasse and after its closure. The results harmonize. Through this part of the river (thirty-five miles above New Orleans) such depths prevail at all stages that great changes may occur without affecting navigation. A valuable opportunity for observation on crevasse effects, however, was afforded at a point where conflicting statements had been made with equal vehemence. Careful surveys were therefore made while the crevasse remained open, and repeated over the same lines in the fall of 1883, after the crevasse was closed, and the flood of that year had passed. The final results of this work are not yet prepared, but the change observed *is scour* throughout the reach below the crevasse, and amounts to approximately, 12 per cent. of the low water area."

This statement establishes, beyond all question, the fact that loss of velocity in the current causes *an immediate* deposit of sediment, for these deposits are made across the bed of the main river *immediately* below the outlet. The last statement also proves that the deposit is removed again as soon as the velocity is restored.

Another important statement which I copy from this report, as it has a bearing upon the inquiry in hand and clearly shows the effect of frictional resistance, is as follows:

"It is observable that the rate of velocity and discharge during a rise increases more rapidly, while the river is still within its banks, than during the higher stages when the banks were submerged, or escape occurs through outlets. At several of the stations the increase of velocity is entirely arrested at about a bank full stage; and before that elevation is reached, absolutely greater velocities, and even discharges, were found than at higher stages when much of the volume was lost over the banks. The loss of volume, through high water outlets, causes both a diminution of velocity and a deflection of the thread of movement of the stream toward the outlet, accompanied by loss of the power necessary to transport the material with which it is loaded. The excess of load is dropped in the bed, decreasing the section below the outlet. When these difficulties recur frequently, and are extended over long parts of the river (as the front of any one of the great basins where volume is alternately reduced and augmented) the injury inflicted on the river as a channel, or as a drain, is cumulative, leading to general deterioration. If the change from low water to flood, with its enormous range in the measure and direction of the river's forces"

[the oscillations being from 40 to 52 feet] "is unfavorable to the development of a navigable and permanent channel, or an effective discharge section, from the different conditions in the same place at different times, it certainly increases these difficulties to allow the introduction of different conditions at the same time in different places. The relief from excessive flood heights which might have been anticipated from the decrease of discharge below the outlet, is not realized, owing to the immediate diminution of velocity and of *vis viva*, and the consequent contraction of sectional area."

It is proper to add that three members of the commission are members of the Corps of U. S. Engineers, of which, until recently, General Humphreys was the chief.

These extracts bear emphatic testimony to the correctness of the opinions and advice which I gave ten years ago, in a letter addressed to the Hon. William Windom, chairman of the Senate committee on transportation routes to the sea board, regarding the improvement of the Mississippi.

After several years of crucial discussion regarding the action of the current upon the sediment, in its relation to the improvement of the Mississippi, and the complete practical demonstration of the existence of the sensitive relation between the velocity of the water, and its burden, by the effect of willow screens or groins across the current at the mouth of the Mississippi, and more recently on the Missouri and Mississippi, the Congress of the United States finally accepted the plan of improvement which I had proposed and had been urging for several years and which was finally recommended by the Mississippi River Commission. The initial works under this plan were commenced about three years ago, and the improvement produced already is of the most gratifying character, and has been very favorably reported upon by committees of both houses of Congress after personal inspection; and quite recently an additional appropriation was made to continue their construction. It is pertinent to state that the plan adopted after so much controversy, differs from any hitherto proposed for the treatment of the river, in the fact that it is essentially a high water treatment, and not a correction of its low water channels. The purpose of the works is to bring its high water surface to a comparative uniformity of width by means of its own deposits. This is being accomplished by the construction of works of the cheapest possible character, through which the floods pass with very slight diminution of current. By this simple means vast deposits of the silt occurs during each flood. As these increase from year to year in height, the flood waters deepen the unobstructed part of the bed, and become more and more confined to one channel which has a width corresponding approximately to the width of the river where the channel is already deep.

In the treatment of other silt-bearing rivers, the training walls or works for the correction of the channel are usually built only half

way up to the flood line. The plan adopted for the Mississippi river is, I believe, the first one in which these wide places are recognized as disturbing elements that must inevitably prevent, so long as they exist, any permanent location of its navigable channel, for the reason that, the frictional resistance of the flood, being increased by these undue widths, a retardation in the volocity must occur at such places, and a deposition of sediment at once follow. The water thus freed from a part of its burden enters the next narrow reach below, where the friction is less, and here it regains its velocity. It is then able to carry its full burden again. This it takes up at once, and thus deepens the bed there. Steeper shores result from this deepening, and this causes them to cave in, and the narrow part of the river widens. Thus an incessant shifting of the channel, caving of the banks, and recreation of the wide places follow each other.

I have dwelt at great length upon the peculiar features of the Mississippi, and on this conflict of opinion regarding the proper plan for its correction, because of the striking similarity of some of its phenomena to those of the Mersey, but more especially to show to what opposite conclusions the most conscientious and accomplished engineers may arrive, if some one law of nature be overlooked, ignored, or unknown by them, in a problem like this.

Among the most important phenomena presented in the estuary of the Mersey, and by which its tidal capacity is kept from impairment, are what are called "*frets*." Their remarkable correspondence with the "*caving banks*" of the Mississippi, can not fail to be noticed by those who have seen both rivers after a flood. That the flood in one occurs but once or twice in a year, and in the other twice a day, does not lessen the evidence that the same forces and similar influences are acting in each, to produce these phenomena.

Before the great importance of this fretting process can be fully understood, it is necessary to comprehend the manner in which the sand and other sedimentary matters are transported by wave action and left upon the banks in the estuary. And here, again, it is necessary to state a few simple truths which appear very commonplace; but they must be remembered as we proceed.

The tidal wave bears a striking analogy to the waves which fall upon the sandy shores of the sea, during and after the existence of a storm.

Waves in deep water produce no continuously horizontal motion. A floating body, undisturbed by the winds or gulf stream, will make no advance in the direction of the waves, if the water be so deep that the subsidence of the crest of the wave does not feel the resistance of the bottom beneath it. Such floating object would simply rise and fall as the waves passed in succession under it. The water affected by the wave would, in such case, act very much as a knot or mark on a long cord would do, if the cord were tightly

stretched between two distant points, and received a blow near one end. A wave would be sent back and forth through the cord, while the knot would simply rise and fall through one nearly straight and vertical track. The case is quite different, however, when the wave feels the influence of the bottom of the sea in its descent. If the bottom be sloping up towards the shore, a slight horizontal motion, or "motion of translation," as it is called, will be imparted to the water by the resistance of the bottom, which will cause its particles to be directed towards the shore. As the wave travels on in shallower and still shallower water, this horizontal motion makes it more and more capable of taking up and transporting sedimentary matters in the same manner that the currents of rivers do. When rolling in over a sandy beach, the water becomes charged with this solid matter, and it is transported up above the mean level of the sea, on to the shore, to a distance proportioned to the height of the wave. As the sand piled up on the shore slopes to the sea, it might be supposed that the retreating wave would carry back with it the whole of its burden. This, however, it can not do, for the reason that, when the flood current ceases, an interval occurs before the ebb current is started. In this momentary pause the suspended matter falls on the shore. The ebb current, although running down hill, starts from a state of rest, and it has less depth and consequently less volume, because subsidence occurs during the period when the currents change their direction, and therefore it cannot carry back all of the burden it brought to the shore. In this way the waves are continually bringing up from the marginal sea bottoms, contributions to the shores, and, unless some littoral or other current be present to disperse them, the banks thus thrown up continue to grow seaward. Wherever a river discharges into the sea, unless it be protected by bold headlands, or have a depth too great to be affected by the wave action, the sea waves pile up a barrier to its outflow. If the river be charged with silt from the territory which it drains, this will also be thrown back and heaped up by the waves, and through the banks thus formed, the river must struggle to reach the sea. This it does by lines of least resistance, and these channels are rarely permanent. It is in this way that the bar of the Mersey has been formed.

We see by this that the channel depth on the Mersey bar, is maintained solely by the *discharge* from the estuary. The waves and tides would quickly obliterate the channels in Liverpool bay, were it not for the outward or ebb currents.

The analogy between the ordinary wave action of the sea on the shore, and the tidal wave in the Mersey estuary, consists in the fact that both create translatory or horizontal currents and both are constantly transporting vast quantities of sand. In great depths the water of the tidal wave has no current or horizontal motion. The velocity of the incoming tidal current in an estuary will, like

the ordinary river currents, depend upon the slope of surface, the volume, and the frictional resistance of the bed. The tidal waters rush up, however, through the estuary, obeying the same laws which the ordinary waves of the sea do, when filling and emptying the miniature estuaries with which the sea beaches are bordered. These come in, in much less time, and fill the little estuaries by their momentum, to a height sometimes far above the mean level of the sea. Both classes of waves, being charged with their respective loads of suspended matter, carry them rapidly up to ends of their excursions, and there, pausing for a time, during which the burden falls to the bottom, they slowly recede to the sea.

The similarity is very close between the sand and silt transported by the Mississippi and that which Captain Hills has collected from various parts of the estuary and bar. The currents of the Mersey are capable of suspending even more of this matter than the Mississippi, both in weight and quantity. Admiral Denham, formerly Marine Surveyor of the port of Liverpool, ascertained, as I learn, from careful measurements of the silt, that the Mersey water in flood, held 1 cubic inch of it to the cubic yard. The low water currents carry much more. That of the Mississippi in flood contains about 1 cubic inch to the cubic yard.

Captain Hills estimates the cubic capacity of the estuary, above the Rock light-house, at 962,000,000 cubic yards, the plane of high water of spring tides, and that the flow of one spring tide of 21 feet into that space is 730,000,000 cubic yards. If this water is charged to 1 cubic inch per cubic yard, and I have no doubt it is, then 3,888 yards of water, will bring in one cubic yard of solid matter, and one such tide of 730,000,000 cubic yards of water will bring in 195,473 cubic yards. Of course much less is brought in by the neap tides. We may, however, assume that the charge of one spring tide will fairly represent the average for each day of the year. If this amount were left in the estuary every day, it would only take about thirteen years to fill it to high tide level, from Rock light-house to Warrington, without the additional silt brought down by the river drainage.

Of course the shallower portions of the estuary would be permanently dried much sooner than the deeper ones, for the reason that the cumulative process would be more rapid in the shallow depths, and because there would be less height of bank needed to dry them.

It follows, then, that any locality or portion of the estuary, in which the tide could flow with its burden of sediment, would fill up to high tide, with a rapidity inversely proportioned to its depth, if from any cause the silt were deposited in it without the current being able to take it back to the sea.

The sediment is sustained in the water by the cohesion of the water with the superficies of the particles. The extent of surface presented by these particles increases with the squares of their

diameters, but their cubical contents, by which their gravity is determined, increases with the cubes of those diameters. If we reduce a sphere to half its diameter we will double the ratio of its surface to its solidity. If its diameter be reduced to one-sixth, its surface will then be six times as great compared with its solid contents as before. Hence the larger particles, as they present proportionately less surface to the contact of the water, require the most rapid currents to suspend them, and are the first to fall when the current becomes weakened.

If the finger be dipped in water and then be placed in contact with dry sand, some idea of the way in which the water suspends these particles may be formed.

If a vessel be filled with coarse, dry sand, there will be a large percentage of void spaces in the sand. If finer sand be poured into the vessel, a large percentage of these voids can be filled by shaking the particles together, without increasing the original bulk. If still finer sand (microcospic particles) be then added, and the whole shaken, an additional percentage of these voids will be filled. This shows that the heavier particles which are first dropped by the current will constitute a large proportion of the total volume of deposit which is thrown down by a *slight* diminution of velocity. In other words, a slight loss of velocity may produce deposits as great in depth as a diminution of velocity twice or thrice as great can produce.

I have referred to the fact that, after repeated trials, the United States Government has adopted the method of using permeable screens or groins to cause deposits for the rectification of the Mississippi, a slight diminution of current being all that is required to throw down immense quantities of the deposit during one season of flood. The deposits resulting in that river in this way, show us, beyond the possibility of doubt, that the loss of current in the estuary of the Mersey, at the change of the tide, must cause immense deposits in it, and it is simply impossible for these depositions to be carried back to the sea by any feebler currents than those which brought them in. It will be seen, as we proceed, that a large portion of these deposits, is left upon the tops of the shallow banks, wholly out of reach of strong ebb currents, and that it is only possible to bring them again in contact with such currents by the undermining action of the "frets" before referred to.

By an examination of the tidal diagrams kindly furnished to me by Captain Graham H. Hills, showing the oscillations of a spring tide at various points throughout the estuary, as high up as Warrington, the following important facts will appear. (See diagram No. 1).

First.—The tide reaches its highest level at Garston and Hale Head, about six miles distant from each other, at almost the same

moment of time; and at this moment the surface is nearly level from Garston to Hale Head, it being only about 1 foot 4 inches higher at Hale head than at Garston. (See diagrams 2, 3, 4, and 5).

Second.—After the tidal wave has reached its highest level at these two places, there is an interval of 2 hours and 40 minutes, during which the water throughout this distance of six miles, remains nearly level and consequently almost wholly undisturbed by any current. The mean difference of level between Garston and Hale Head, during this period, is less than twelve inches, or two inches per mile; and part of the time it is almost level, the water being then only 5 inches higher at Hale Head than at Garston. During this 2 hours and 40 minutes, it has subsided at each place through almost precisely the same vertical distance, namely, about 13 feet 5 inches. During this period of quiet repose, the deposit has been falling to the bottom. At the close of this period, the ebb has uncovered a bank 7,500 feet in width, measured across a section of the estuary a short distance below Hale Head, leaving only about two-fifths of the entire width of the estuary at that place covered with water. At the same time it has uncovered 720 feet in width across the banks about a mile above Garston; and it has almost dried half the width of the estuary on a section midway between Garston and Hale Head. In the next 1 hour and 20 minutes the slope from Hale Head to Garston has been greatly increased, for during this period the water has fallen 7 feet 7 inches at Garston, and only 3 feet 8 inches at Hale Head, giving a slope of surface of 10½ inches per mile. This great slope has induced a rapid current, but an additional drying of the banks at Hale Head has occurred, while, midway to Garston, 7,380 feet of width of the estuary has been dried, and is wholly out of the reach of this rapid current, being nearly one-half of its total width; while near Garston, a width of 6,480 feet of banks has been left dry. Five hours after high tide at Hale Head, the tide has fallen at Garston 26 feet 1 inch, and the slope has increased between Hale Head and Garston to 17½ inches per mile, while the dried area of the banks has been largely increased. At the sixth hour after high tide the level at Garston has fallen to 30 feet 6 inches below high tide, and has increased the slope from Hale Head to 25½ inches per mile. At the end of the seventh hour, it has fallen at Garston to 32 feet 6 inches below high tide, and it then has the enormous slope of 29½ inches per mile. At the end of the eighth hour, its slope is somewhat less, but still very great, being 21½ inches per mile.

We see, therefore, that for five hours and twenty minutes after a period of almost perfect repose, an extremely energetic current has been maintained, down to Garston, and that during the last four hours of it, when it was most rapid, more than half of the surface of the estuary was wholly above its reach. Only after a repose of 2 hours

and 40 minutes, and a fall of nearly 13½ feet at Hale Head and Garston, does the low water volume of discharge begin its vitally important work. This consists in undermining, tumbling down, and carrying towards the sea, the banks that are being constantly and rapidly built up over large areas of the estuary by the semi-diurnal contributions of the flood tide. In this most essential work, the ebb tide is, only to a slight extent, increased by the discharge of the Irwell, the Weaver and the Upper Mersey.

If this fretting process be stopped, as it certainly will be if the proposed canal works are built, these deposits must inevitably accumulate upon the banks on each side of the proposed channel and become permanently dried, and the tidal capacity of the estuary must be in a little while greatly diminished.

In this connection I beg to call your attention to the last Chart in Admiral Spratt's report for 1880, showing the meanderings of the low water channel of the estuary between Runcorn and Garston from 1825 to 1880, by which it will be seen that the banks in every part of the estuary, throughout its greatest width, from Runcorn to Garston, have at one time or another during this period, been attacked by this fretting process; and, through it the vast accumulations left by the flood tide, entirely out of reach of effective ebb currents, have been cut down and carried into the lower estuary.

It must be evident, therefore, that if the low water channel be permanently located as proposed, its wandering character will be gone, and therefore the shoal banks must soon be raised to the level of the highest floods and become equally permanent with the proposed channel, for they will be out of the reach of this undermining process. In proportion as the shoals grow in height, the accumulations of deposit upon them will become more rapid, because, the depth of water being less, the ebb currents over them will become less and less able to take away what the flood has brought on to them, until finally, they will become permanent, and covered with vegetation. As the estuary will in this way become more and more contracted at high water, it will have, in the part between Runcorn and Garston, a rapid tendency to convert itself into an ordinary river. The shore currents are always the most sluggish in rivers, and the deposits will be left upon them until they will become narrowed in, and so steep that any further deposits upon them will slide down to the stronger current where the channel is deeper. Its shores will then have attained their nominal angles of repose. In this way, the stream will be narrowed in down below Hale Head, and ultimately to Garston. If the proposed channel could be immediately created, the tide would rise somewhat higher at Hale Head, because the channel would then be more direct and deeper; but this additional rise could not be great, inasmuch as the quantity which will come into the estuary is controlled largely by

the rock-bound channel at Liverpool. It would, I think, however, if it could be *immediately* constructed, be sufficient to appreciably improve the channel over the bar. But, as it will take years to complete it, the silting on the banks will, no doubt, fully neutralize this tendency to increase the inflow of tidal water. As soon as the proposed channel is completed, the fretting process will be stopped almost wholly, and the destruction of tidal capacity will rapidly follow.

After the proposed channel shall have been first dredged out and thoroughly defined by its rock walls, the scour of the low water current through it will be so great, before any extensive reduction of tidal capacity has occurred, that it will need no further dredging. On the contrary, I think it will become very deep, and that its walls will be extensively undermined, and, unless the stone of which they are composed is in large masses, much of it will be found at the lower end of the channel, opposite Garston, where it will form the nucleus for permanent shoals. The present low water current, with its enormous slope, must be capable of removing stones weighing from fifty to one hundred pounds. I have known stones of such weight to be moved down the bottom of the Mississippi river in currents not so strong as these must be. In putting in the piers of the St. Charles bridge over the Missouri river, a remarkable case of this kind came under my notice, as I was a member of the executive committee of the directors, though not the engineer. At this location a telegraph cable had been laid across the river, and was afterwards broken and disused. One of the piers was put down onto the solid rock, through a bed of boulders, or large round stones, several feet deep. Beneath these boulders the cable was found. Many of these stones were as large as a peck measure. They were evidently brought down by the current after the cable was laid.

After the loss of tidal capacity in the upper estuary shall have been very considerable, as it soon must be after the proposed works are built, the channel will begin to be reduced in size in the manner which I have endeavored to describe, and its depth will then have to be maintained by dredging.

The momentum of the tidal wave would then cause the flood to rise higher in the river, for a few miles above Runcorn, than at present, and its shores would be built up, probably, several feet above the present high tides by accretions that would be dropped on them by these tidal overflows.

When the current of a silt-bearing river loses any part of its velocity, the larger and heavier particles of solid matter which it has in suspension are first dropped. The finer particles, needing less velocity to sustain them, are held longer in suspension. For this reason, the shores of a river which are from time to time overflown are always higher than the land more distant from it. On the Mis-

sissippi river, the shores are from twelve to fourteen feet higher, generally, than the land half a mile back; and on some small silt-bearing streams which I have had occasion to examine, the deposit has been dropped along on each shore in the form of an embankment so high and narrow as to produce the impression that it was purposely thrown up by man.

Therefore, when the banks of the estuary on each side of the proposed channel shall have been built up nearly to the level of ordinary high tides, it will be found that the deposits are higher along these shores than back from them. As the velocity of the flood water by which the sand was sustained is reduced as soon as it overflows the flat top of the shores, the heavy particles will be immediately deposited while the lighter ones will be carried by the overflowing water back towards the present shores of the estuary. Hence there will remain, for many years, between Runcorn and Garston, large areas of swamp land on each side of the proposed channel. These swamps will only receive the finer argillaceous matter and microscopic sand particles, and these will, at last, be brought over them only with exceptionally high tides. They will continue, therefore, as marshes for a long time after the tidal capacity of the estuary shall have been reduced, unless they are reclaimed by artificial means.

In this way, the features of an estuary, above Garston, will be rapidly changed into those of a tidal river, simply by permanently fixing the present wandering low water channel, and thereby stopping its semi-diurnal "sapping and mining" attacks at the bases of the enormous banks created by the flood tides. The Mersey above Garston, with its swamps on each side of it, would then present the same appearance (only on a little larger scale) that the Holpool gutter and the Frodsham marsh lands now do. This gutter and its marshes were once a considerable estuary which finally silted up because, from some accidental or natural cause, the fretting process of its low water channel was interrupted.

Frets would, possibly, occur through the banks on each side of the proposed canal channel, for some time after the channel was formed, and would, to a slight extent, delay, for the first two or three years, the rapid building up of the banks, by undoing the work of the depositing process; but these frets would occur only in the part of the estuary between Hale Head and Garston. The estuary being narrower above Hale Head, the water there would all drain into the central channel.

The amount of excavating work which a low water channel is capable of doing, in the way of cutting down and re-distributing the banks, is limited by the volume and the velocity of the water which flows through such channel. As there is only a certain quantity to be dischaged at each ebb, its excavating power or fretting ability will, therefore, be most energetic when all this water is flowing in

one channel; so, if fretting occurs, even for a short time, after the proposed channel is made, it must be done with little insignificant channels on each side of the proposed one, for much the largest portion of the low water discharge will, certainly, be through the proposed channel which is to be both deep and central, and, as the sides of it are to be protected by stone revetment, the fretting process must be very effectually destroyed by it, above Garston.

This fretting process is just as necessary to keep the estuary from silting up, as the tidal basin of the estuary is necessary to maintain the present depth on the bar.

For the reasons given it will be seen that it is equally dangerous to erect any cross walls or groins, even up to half tide, through the estuary of the Mersey, for the purpose of improving the navigation of its low water channel, as has been, I believe, suggested, (not, however, by the Manchester Canal promoters,) because these groins would produce similar effects.

Silt-bearing streams flowing through alluvial beds, if contracted in width, will *recover* such area of cross section, by deepening, as their floods may require, for their discharge. This is true of the Mersey.

This second proposition is equally true, namely: The cross-sectional area of silt-bearing streams, if permanently deprived of a portion of their flood waters, will reduce their sectional area until it is only sufficient to discharge the remainder.

A third proposition in this connection is no less true, namely: Silt-bearing streams, when permanently deprived of a part of their flood waters, assume steeper slopes of surface.

Accelerated velocity of current, resulting from the contraction of the channel, takes place under the first proposition, and causes a removal of deposit and consequent deepening. Loss of velocity occurs in the last two cases, and deposits are thrown down in the channel, by which it loses capacity of cross section, and this depositing only ceases after it produces a steeper slope, by which the current attains a velocity which prevents further deposit.

With these three axioms we may correctly forecast the future changes that will occur in the Mersey, at least above Garston, if the proposed channel is made.

A moment's thought about frictional resistance will teach one that if the wetted perimeter of the estuary were reduced from three miles, its present width, to one quarter of that width, and had such depth as would produce an equal area of cross section, the bed of the estuary thus narrowed would, with the same slope, discharge nearly four times as much water as the estuary can now do where it is three miles wide, because it would have but little more than one-quarter as much frictional resistance as it now has.

If such a narrow and deep channel were, by some stroke of magic, constructed to-day, the truth of the second proposition would be

seen in a little while, for such a channel being too great to maintain the requisite velocity of current, with even the present volume of discharge, would begin to be reduced by deposits on its bottom and on its shores, until it became narrower and shallower, and properly sized to receive and discharge the floods that would then enter. But these would be much smaller than before, for they would be only, at first, three quarters of a mile wide, instead of three miles, and although the new channel would be much deeper than before, its depth below low tide would be always full, and hence that part would admit no additional water. It would, therefore, only fill and empty to about the same depth as at present.

As soon as such channel as this became reduced to the size, in width and depth, actually required by the demands of this greatly reduced volume of flood waters, the third axiom would begin to manifest itself, namely: That silt-bearing streams, when deprived of their usual volume of flood waters, assume steeper slopes of of surface. Therefore, much of the silt carried up by the tide in the higher reaches would remain there, and it would be increased in slope and reduced in size, to accommodate only the land drainage.

To give some idea of how rapidly the capacity of a channel to pass a given volume of water increases with an increase of its depth where its width is restricted, I beg to refer to the annexed diagram taken from a report which I had the honor to make to the United States Government, in 1882, as a member of the Mississippi River Commission; and in explanation of the diagram I make the following extract from the report:

"Let us suppose the Mississippi river in flood to be 118 feet deep and 3,000 feet wide, and that an additional rise of 5 feet then occurs. The increase of friction in this case is only on the two sides of the channel which are in contact with this additional 5 feet of depth. This friction or wetted surface on the two sloping banks would probably not exceed an aggregate width of 20 feet. The water flowing in the stream before this addition was made to it had a frictional surface of about 3,100 feet in width. The 5 feet additional rise increases the cross section in such case from about 200,000 to 215,000 square feet, or 7½ per cent., while the friction will have been only increased about two-thirds of one per cent. We see, therefore, that the ratio of friction decreases with an increase of volume, and as a result of this, we must have an increase of velocity of current and consequently an increased capacity of discharge in the stream."

At Carrollton Humphreys and Abbott took accurate measurements of the mean velocity of the river, and of its rise an fall, and their report contains extensive tables of the discharge per second at that point through a series of years, including the floods of 1851 and 1858. The diagram is intended to represent a cross section of the river at that place. The upper line indicates the height of the flood between the levees or embankments shown on each side; and this line is 6.8 feet above the lower one; the channel at the time of the highest

water was about 122 feet deep. From Humphreys and Abbott's tables it is shown that on August 25th, 1851, when the river stood at the lower level, being just bank full, its mean current was 3.38 feet per second, and its discharge was 572,388 cubic feet. On March 19th when only 6.8 feet higher, it discharged 1,149,398 cubic feet per second, or more than double when only 6.8 feet lower. The mean current velocity was 6.19 feet per second, the velocity having increased 2.81 feet per second, or 85 per cent.

I quote again from the report:

"The river here, at the lowest stage, was 115 feet deep. Hence there was an increase of only 1-17th part of its total depth required to produce this astonishing difference in the discharge of the river."

The accepted formulæ for estimating the cross-section of a channel of such form as the deep one suggested would naturally take (that is corresponding nearly to the arc of a circle), enable us to form a reasonably accurate estimate of the size required to discharge the present tidal water, where the estuary is 339,975 square feet in sectional area, and the wetted perimeter is 12.010 linear feet:

From the formula: $v = c\sqrt{rs}$.

where $v =$ velocity.

" $c =$ co-efficient determined by experiment.

" $s =$ surface inclination of water.

" $r = \dfrac{\text{sectional area}}{\text{wetted perimeter}} =$ hyd. mean radius.

Let us assume a segmental channel with tangential slopes of 1 to 2. We shall then only require a sectional area of 176,365 square feet, with a surface width of but 1,550 linear feet, and a central depth of 183 feet. This channel would be quite sufficient to discharge the same amount of water in the same time, with the same slope of surface, that the estuary of Garston can do with the present width and depth.

The annexed diagram, drawn to natural scale, will serve to show at a glance the relative size of the present cross-sectional area of the estuary, and the segmental one resulting from the formula.

If the channel of the promoters were once completed with its proposed cross-sectional area, it would have a tendency to enlarge and deepen and develop its sides up to high tide, to something approximating the form and size of this theoretic section, provided the present amount of tidal water remained to be discharged through it. But this could not remain, for the reasons given. Before any considerable decrease in tidal basin occurred, however, the proposed channel would be found to be insufficient for the discharge of the tidal water that would at first be attracted to it; and the result would be

an undercutting of the stones with which it was lined, not only on the sides next to the channel, but on the outer sides of the revetments. In other words, the channel, as proposed, would be at first entirely too small for the ebb discharges, and in the effort of the trained waters to enlarge it, the stones, except the very large ones, would be disarranged and rolled down toward Garston, whilst those that were not carried down by the pent-up current would sink into the quicksand.

During the development of a permanent channel, and the formation of the banks on each side of it, vessels ascending or descending the channel would be exposed to great dangers because of their liability to sheer in it. "Sheering" is a term in general use among nautical men, to express the sudden deviation and loss of control to which vessels are frequently subjected in narrow channels. As I have found no published explanation of the causes of sheering, and as it is of very frequent occurrence in the Suez and other canals, it may not be out of place to explain it here.

A vessel, to be under control of the rudder, must be moving through the water under the impulse of some force. In this condition, when going ahead, the water displaced by the wedged shape of the vessel is raised at the bow on each side of the ship. If the vessel be passing through a canal or other narrow channel, the water she displaces must pass on each side, or underneath the bottom of the ship, and take its place behind her. If she be a little nearer to one bank of the canal than the other, the wave at the bow on the narrowest side must be necessarily higher than the one on the opposite side, because of the greater difficulty of its passage to the stern. If great depth be under the ship at the time, a sheer will not necessarily occur, because the water, which would otherwise become higher on that bow, would equalize itself under the keel of the ship. But if the ship be of deep draught, and near the bottom of the channel, the height of the wave on each bow is not so quickly equalized, and the elevation on the side nearest the bank is not reduced, and its hydrostatic pressure and the resistance which the water feels between the bank and the bow of the ship on that side force the vessel off from that bank. In river parlance, "she runs away from the shallow water." The only means which the pilot has to correct this is by the rudder, and that, unfortunately, must be used at the moment to force the stern of the vessel away from the nearest bank also. Thus, the effect of the rudder and the effect of the wave at the bow are precisely alike; that is, the ship is impelled broadside against the opposite bank, where she is usually left aground, only to be relieved at a higher tide.

Of course the sheering of a vessel under the circumstances I have described would not be likely to take place, except when the surface of the water in the proposed channel was nearly down to the top of

the training walls or the shores which would develop alongside of the channel.

The flood tides when coming in will cross the proposed channel about three miles above Garston, and cross currents will be created thereby, which would be very dangerous to vessels navigating the channel at such times. The danger of vessels being wrecked in a narrow channel liable to such cross currents, where the tidal oscillations are very great, must be so apparent as not to need discussion.

It may be claimed that, because the banks would be covered with less and less water after the proposed channel is formed, their growth would not be cumulative, for the floods would have less power to transport the sediment. But it must be remembered that the velocity of the flood tide is much greater while rising through the last 13½ feet of its height between Garston and Hale Head, during which these shoals are covered, than in falling through that height. When the tide is rising, it is 6 feet higher at Garston than it is at Hale Head, when the height of the latter is 13 ft. 5 in. below high tide. Hence, if we remember that *volume* is one of the two elements which produce the current, it will be seen that this slope of 6 feet toward Hale Head, being combined with an immense volume, must produce a much greater velocity than an equal slope in the opposite direction can do with much less volume, for the same slope is only attained from Hale Head to Garston when the volume has been reduced at Garston by a subsidence of 22 feet. Besides, the ebb slope lacks the tremendous momentum of the tidal wave, for the ebb starts from a state of rest.

It may be supposed by some that the steep slope of the bottom from Hale Head to Garston, over three feet per mile, will increase the velocity of the ebb; but the inexorable law stands in the way of this, for the current is the result of the surface slope and the volume, taken together, while the rate of current, or velocity, is controlled by the friction of the bed. A distinction between *current* and *velocity* must be remembered. The bottom only regulates the speed of the current by its friction, and, as the ratio of friction decreases with an increase of depth, it must follow that if the bottom, from Garston to Hale Head, were thrice as deep as it is, and were level from Garston to Warrington, the velocity induced by the difference of surface level from Hale Head to Garston would be much greater over this deep water than it now is over this steep but shallow bed.

We see by the foregoing facts the important bearing which the question of the sensitive relation between the velocity of the current and the quantity of sediment transported has in this discussion. That the deposit forms immediately after any loss of velocity is most indubitably proved by the results to which I have referred, on the Mississippi river. If any considerable period of time existed between the loss of velocity and the dropping of the sediment,

it follows that the deposition would take place at a proportionately greater distance below any gap which occurred through the Mississippi levees in flood time. But the loss of velocity of course accurs at the moment that a part of the river flood is withdrawn from the main channel, for the depositions are found immediately below the gap. If these solid matters, after a loss of velocity, could be held in suspension, as has been hitherto believed by a large class of engineers, it would follow that the sediment of the Mersey might be brought in from the sea and taken out again in the same manner, without any detriment to the estuary, and that for the same reason the burden of the Mississippi floods could be carried on by the weirs or outlets which have from time to time occurred through the levees, and thus form no obstruction to its channels. These floods, with their slightly diminished currents, would pass on through the willow screens that are being erected to-day on the Mississippi river for its improvement, without causing any deposition of this burden; but, in the face of the innumerable proofs of the synchronism between the loss of current and the deposition, it is idle to discuss this point farther. Without the existence of such relation, it is simply impossible for any engineer to give a logical explanation of the frets and wanderings of the low water channels of the Mersey, or the existence of any of the banks and channels which are to be found throughout the estuary and in Liverpool bay; whereas, all the various phenomena relating to the alluvial deposits and sea sands of the estuary, and to the formation and phases of the bar at its mouth, are readily explained and easily understood by recognizing such relation.

These conclusions can not be logically challenged or successfully ovorthrown without showing, first, that the laws or principles on which they are based, and which I have purposely set forth in as simple language as possible, are unsound; or, second, without showing that the conclusions themselves are not in strict agreement with these laws.

The important part performed by the continually shifting low-water channels of the estuary, during the lowest stages of the tide must be perfectly apparent when it is remembered that the quantity of sediment which the current is able to carry forward increases with the square of the velocity. The low-water currents, with their enormous slopes, have therefore the power of transporting very large quantities of the sediment toward the sea, while the incoming tide, rushing over the bar with great rapidity, comes through the narrow neck at Liverpool thoroughly charged with its load of suspended matter, and in this condition it is unable to carry any additional burden; and thus the sediment which is brought down during the longer periods of the ebb flow, remains at the lower end of the estuary, comparatively undisturbed by the incoming flood; and this is taken up again and carried out to sea with the earliest of the ebb

currents, for at the time these ebb currents are first started, in the lower estuary, there has been a period, of more or less duration, during which the water there was in repose, and during which its load of sediment was dropped. This water is, therefore, in a condition to take up a fresh load as soon as the currents in it are created by the ebb below Liverpool. As the first currents created in this quiescent and unloaded water will be at the lower end of the estuary, where the deposits brought down during the previous ebb remain in waiting, they will be then taken up and carried out over the bar.

In conclusion, I beg to state that the inevitable result of building the works proposed by the Manchester Canal promoters, between Garston and Astmoor Marsh, will be to destroy, within a few years, almost wholly the tidal capacity of all that portion of the estuary which lies above Garston. They will also destroy the present access to the Garston Docks and Ellesmere port. Below the termination of the intended works, the disturbance of the regimen of the estuary will be so great as to increase the Pluckington shoal, and thus endanger the access to the docks as far down as Prince's Dock.

The conversion of the estuary above Garston, into a tidal river will be followed by the reproduction of the sand banks, low water channels, and fretting processes, from that point down to the Pluckington shoal, by which this, the lower part of the estuary, will be in turn deprived of its present tidal capacity. As the destruction of the tidal capacity of the estuary proceeds, the depth over the bar in the Queen's Channel will be proportionately lessened, and the crest of the bar will be drawn farther inland.

These results will certainly follow the formation of the proposed channel. How soon they will occur cannot be foretold accurately; but in my opinion the injury will be so apparent as to make itself felt within two or three years after the construction of the works, both upon the depth in the Queen's Channel and in the access to the various docks to which I have had reference.

If the works are built, I think fifteen years will not elapse before a reduction of at least two-thirds of the present tidal capacity of the estuary above Garston will occur.

The fact that the tidal capacity of the estuary has diminished very little since Giles' survey in 1819, proves that the daily contributions of deposit brought in by the flood tides have their average equivalent of it discharged again by the ebb tides. This shows beyond the possibility of doubt that there has been during this long period a maintenance by natural laws of an equilibrium between the forces so continually and energetically at work in the estuary, in the opposite operations of deposit and scour. Where such vast commercial interests are dependent upon the maintenance of this equilibrium, it is certainly the part of wisdom not to do anything to interfere with the natural processes by which it is preserved.

I avail myself of this opportunity to express my sincere thanks to Mr. George Fosbery Lyster, Chief Engineer; Captain Graham H. Hills, R. N., Marine Surveyor; and Mr. Anthony George Lyster, Assistant Engineer, of the Mersey Docks and Harbour Board, for their extreme courtesy in supplying me with every information in their power, and in every way aiding me in the important enquiry with which I have had the honor to be charged.

GALVESTON HARBOR.

LETTER TO THE EDITOR OF THE GALVESTON NEWS.

ST. LOUIS, April 28, 1884.

Dear Sir,—On my return from England, a few days ago, my attention was called to the official reports of General Newton, Chief of Engineers, U. S. A., and Colonel S. M. Mansfield, of the same corps, on Senate bill No. 1652, authorizing me to improve the harbor of Galveston, in accordance with the wishes of the people of Texas, as expressed by the mayor and council, and the representative citizens of Galveston and the Legislature of the State.

As these reports contain several inaccuracies, which place my proposition in a wrong light, justice to myself and consideration for the citizens of Texas, who have so heartily supported the proposal, require that I should point them out.

Col. Mansfield says:

"Eight months are allowed him in which to begin operations, and twenty-four months more are allowed him in which to put two feet more water on the bar, for which the Government is to pay him $1,000,000 a foot, thus providing for an additional two feet of water in two years and eight months' time from the passage of the bill. Upon the obtaining of another foot of water the Government is to pay $500,000, and the next foot $500,000, and so on during the sixteen years in which Mr. Eads is allowed to put thirty feet of water on the bar at high tide."

Col. Mansfield states that "the first appropriation for the improvement of the harbor, after the adoption of the project, was made in

1874." As the work has been prosecuted by him and his predecessors ever since, with a gain of only two feet, it is the most natural thing in the world for these gentlemen to suppose that I will not be able in two years and eight months to do any more than they have done in ten years.

They overlook the fact that there is nothing in the bill to forbid my making a deep channel as soon as I can. They forget, too, the stimulus with which I should prosecute the work, and that which has animated them. I can get no money until specified depths are obtained; therefore it would be to my interest to secure the greatest depth at the earliest moment.

Their money has been supplied for the last ten years by a confiding Government on faith alone, absolutely regardless of results, and they now ask it to advance three-quarters of a million more on the same security. If my plans fail, I and my associates would bear the whole pecuniary loss, and I should lose my professional reputation also. If theirs fail, the public treasury pays the loss, while they lose neither rank nor money, nor in any wise endanger their promotion. On the contrary, they may be charged with still graver responsibilities.

The plan now being executed at Galveston was designed by Major Howell, and was approved in 1874 by a board, of which Gen. Newton was a member. Both officers earnestly strove to defeat the improvement at the mouth of the Mississippi River, and urged the Fort St. Philip Canal instead. Immense interests, affecting the people of the whole Mississippi Valley, then depended upon the issue. Time has shown that a grave error was made in the vigorous opposition which these gentlemen manifested to my plans at that time. Since then I have been repeatedly urged by citizens of Galveston to express an opinion as to the success which would attend the present attempt to improve Galveston harbor. I have carefully avoided doing so until appealed to by the almost unanimous voice of its citizens last winter.

Desiring to avoid a repetition of the controversy which attended the improvement of the mouth of the Mississippi, I declared in my letter to the mayor and council, and afterward to the Texas Congressional delegation, that I would not go before Congress to urge the proposition contained in Senate bill No. 1652. But as Gen. Newton and Col. Mansfield have chosen to place me upon the defensive in the matter, by an unfair presentation of what I promise to do in the bill, I am justified in comparing promises and results with them, and in defending myself and my proposition.

To support their request for this additional sum of money, they simply express their confident opinion that an 18 ft. channel will result from the completion of the plan, while all they can show for a million and a half of money and ten years of time already spent on it, is one jetty wrongly located, 2½ to 14 feet high and 4¼ miles long,

and the utter wreck of another one, on the other side of the channel, called a "gabionade," on which it is admitted that $245,000 was spent before it was abandoned. The result secured by this ten years of effort and a million and a half of dollars, is, according to Col. Mansfield's own report,* a permanent deepening of from four to eight feet *on the wrong side* of the existing jetty, "and an increased depth of only two feet in the jetty channel," which the drifting sands "tend continually to obliterate." Even the existence of this two feet is denied by prominent citizens of the place.

Gen. Newton says:

"The case can be plainly stated as follows: Col. Mansfield, with the expenditure of $750,000 and two seasons' work, will obtain an increase of depth exceeding two feet, and probably reach five feet or six feet; while Mr. Eads and associates promise, after a period of two years and eight months after the passage of the bill, to gain two feet of depth for the expenditure on the part of the Government of $2,000,000."

If these gentlemen were familiar with the history of the Mississippi jetties, they would not believe that I intend to be two years and eight months in getting two feet of water at Galveston; for on the 4th of March, only one year from the date of the approval of the jetty act, the Mattie Atwood, drawing thirteen feet of water, passed out through the uncompleted works. Although we had, as in the present bill, eight months in which to begin work, and two years thereafter in which to accomplish specified results, we commenced them in about three months, and deepened the water five feet in nine months thereafter; and in two years and eight months after the approval of the law we had secured a twenty-two feet channel, having deepened the bar fourteen feet. They assume that I will be sixteen years in getting thirty feet of water, whereas one of my chief reasons for consenting to undertake the work is the conviction that I can secure at least a twenty-two feet channel in two years after commencing it, and twenty-seven or twenty-eight feet in the next two years. Even if I had said that I should require sixteen years to get thirty feet, they would not be justified in adversely criticising such a proposition, because sixteen feet in sixteen years is five times as rapid a rate as they can show.

Col. Mansfield in his report, says:

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* Col. Mansfield says: "A careful statement of the changes continually going on and the causes which produce them will explain why there has been no greater increase, and also furnish the proof of ultimate success of the work." He says further: "This drifting sand is banked against the north side of the south jetty, and thus tends continually to obliterate the jetty channel; the overflow water, on the other hand, has excavated a deep trench along the south face of the jetty. The amount of deepening due to this overflow varies from four to eight feet, and remains permanent."

"What is to be gained by this procedure I am unable to say; I may be allowed, however, to express my conviction that the passage of this bill is not warranted by the facts, and that in the single respect of deep water it is entirely uncalled for."

If he accepts his own assumption that I am to get only sixteen feet in sixteen years, and his own statement of what has been actually done in ten years, a little arithmetic will show Col. Mansfield that it will take eighty (80) years to get sixteen feet more, at the rate which he reports; and will, therefore, disprove his declaration that "in the single respect of deep water it is entirely uncalled for."

Col. Mansfield says:

"The government is to commit itself to the payment of $7,750,000 during the next sixteen years for about what the government can secure by continuing the present work during the next two years for $750,000."

I think this statement will be found to be inaccurate. Gen. Humphreys, in his report (October 20, 1874, article 1, page 73), under the heading of "Improvement of the Harbor of Galveston, says:

"Capt. Howell submitted a report upon the results of the survey he had been directed to make for the purpose of determining and estimating the cost of some plan of improvement calculated to give an eighteen foot entrance to this harbor."

And Capt. Howell, June 19, 1873, says:

"The object of the survey, as stated in your letter of instructions, was to determine and estimate the cost of some plan calculated to give an eighteen foot entrance to Galveston Harbor."

Gen. Newton says in his report:

"The mode of improvement at Galveston has been reported on by boards of engineers in 1874-75-76-80; two jetties on the south and north were recommended as necessary, and this view has since been held without a change in this office."

As the plan has not been changed, according to the statement of Gen. Newton, and as a reference to the foregoing reports shows that the plan only contemplated eighteen feet of depth, Col. Mansfield is hardly justified in asserting that with the $750,000 which he needs to complete that plan, the government can obtain a thirty feet channel into Galveston harbor. I am further justified in assuming that the present plan of improvement does not contemplate securing a channel of more than eighteen or twenty feet, from the following statement in Gen. Newton's report:

"The north and south jetties, placed according to the official plan, can, by an extension into deep water, and by the construction of auxiliary works if needed, be made to develop all the depth of channel which the nature of the locality will admit."

He says further:

"Should Congress be resolved to make a change in the administration of this work, at least it will be for the interest of the service to wait the construction of the north jetty and the observation of its effects, which will lead to the possession of facts and data calculated to throw a needed light upon the amount necessary to be expended for obtaining a proper depth on the bar."

As Gen. Newton was a member of the board of 1874, this latter statement possesses remarkable significance. It shows clearly that the plan adopted then, and which has in ten years produced really no substantial benefit, is simply an experiment, from which it is hoped to obtain "the possession of facts and data calculated to throw *a needed light*" upon the problem in hand. This "needed light" should have been possessed in 1874 by these engineers. The want of it then caused Gen. Newton and Major Howell, while groping in the dark over the Galveston problem, to declare that the plan of improvement by which I have secured thirty-three feet of navigable depth, where only eight feet existed, at South Pass bar, would prove a complete failure. Had their advice then been taken, the producers in the Valley of the Mississippi would to-day be waiting for the completion of a canal through the swamps of Louisiana, instead of saving, as they now do every year, and as they have done for the last five years, five or ten times the amount paid by the government for building the jetties. These works have advanced New Orleans to the rank of the second exporting port in America. These facts constitute a fulfillment of the promises made in the jetty bill of 1875.

Gen. Newton now advises the government to wait two years longer, until the experiment at Galveston shall have shed the *needed light* on the engineers in charge, to show how to deepen the channel into the harbor to the full depth acquired by the immense commerce which will seek that outlet. If this be done the producers of Texas and the vast territory tributary to Galveston must continue to pay lighterage and high freightage on their products, as they have been doing heretofore, and the great future which awaits the city itself must be delayed until the result of an experiment supplies such a knowledge of hydraulic engineering "to the service" as it should have possessed ten years ago. The interests of *the service* are to be made paramount to those of Texas.

It is evident from the foregoing that it is unfair to compare the results which are guaranteed in the Senate bill for $7,750,000 with those which are expected to be produced by the completion of the present plan, inasmuch as to produce thirty feet of water by the latter involves, according to Gen. Newton's own admission, an extension of the jetties into the deep water, and the possible construction of auxiliary works for which no estimates whatever, either

of time or money have been submitted. Nor has any plan for securing thirty feet, or any other depth over the inner bar, been submitted, nor is its cost included in the $750,000 asked for. The works which I deem necessary to deepen the inner bar to thirty feet will cost as much as Col. Mansfield asks for his north jetty.

The plan being carried out at Galveston was conceived in the absence of the "needed light," and is what may be termed "a submerged system of jetties," and being planned without recognizing the principles which control the problem at Galveston, it cannot be made successful by the expenditure of five times the sum asked by Col. Mansfield, even to the extent of securing twenty feet of water. It is an attempt to improve upon tbe "jetty system," in which the very essence of this system is violated. No such depth as I propose, can be obtained unless works, properly located, are built up entirely above overflow, from the land out to the deep water beyond the crest of the bar. It is, therefore, deceptive and unfair, as well as idle, to attempt to compare the cost of a system of low submerged jetties, from two to fourteen feet high and not extending to deep water, with those that must, to be successful, extend out into it, and be built to twice or thrice the average height of the other, for the reason that the cost of both systems will be as the square of their heights, other things being equal, while the extensions into the deep water will increase in a much more rapid ratio.

Yours respectfully,

JAMES B. EADS.